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AIR FORCE AVIONICS LABORATORY

STANDARD ELECTRONIC MODULE RADAR LIFE CYCLE COST COMPARISON

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The report presents a life cycle cost (LCC) analysis of an airborne weather radar system functionally similar to the Standard Electronic Module Radar (SEMR) and compares the LCC estimates for this system to previously developed LCC estimates for the SEMR. The SEMR has been designed, fabricated and tested as a demonstration of the concepts of the TRI-service Standard Electronic Module program. A previous study analyzed the LCC characteristics of the SEMR and developed LCC estimates for specific implementation alterna- → over

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tives. The APQ-122V(5) radar design was selected for the LCC comparison as a representative example of solid state systems composed of custom subassemblies. The LCC analysis of a SEMR-equivalent of APQ-122 system was conducted using procedures and assumptions which were consistent with those used in the previous SEMR LCC study. ~~The~~ results presented in this report include a comparison of baseline LCC totals and subtotals, a comparison of the sensitivity of the two sets of LCC estimates to operational parameters, and an analysis of how the critical assumptions used in developing the SEMR-equivalent APQ-122 LCC estimates affect the baseline comparison. The primary finding ~~of this study~~ was that, when using available data and consistent analytical procedures, the baseline LCC estimates for the SEMR-equivalent APQ-122 system were approximately 40% ~~(forty percent)~~ lower than the SEMR estimates. Sensitivity analyses did not significantly alter this finding.

PREFACE

This technical report was prepared for the U. S. Air Force Avionics Laboratory in compliance with CLIN # 1, CDRL sequence Number 4, Contract # F33615-78-C-1508.

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EXECUTIVE SUMMARY

The U. S. Air Force Avionics Laboratory has sponsored the design, fabrication and testing of an advanced development model of the Standard Electronic Module Radar (SEMR). The SEMR design is the first application of the components and concepts of the Tri-Service Standard Electronic Module Program to an Air Force avionics function. It is functionally comparable to the APN 59/B weather radar installed in C-130, C-135, and C-141 aircraft. In order to evaluate the life cycle cost (LCC) characteristics of the SEMR, two parallel life cycle cost studies were performed for the Avionics Laboratory by Battelle's Columbus Laboratories and the Norden Division of United Technology. Subsequently, the Air Force decided to sponsor a study to develop life cycle cost estimates for a functionally equivalent solid-state radar employing the typical design concept of custom sub-assemblies and compare the estimates to the previously developed SEMR estimates. This report presents the results of the LCC comparison study.

The approach followed in this study involved:

1) Selecting a solid-state radar for use in the comparative analysis.

2) Collecting the necessary acquisition and logistics data.

3) Formulating baseline LCC estimates for three force options (the C-130/C-135 force, the C-141 force, and a combined force) using procedures and assumptions consistent with those used in the previous Battelle study of the SEMR.

4) Performing sensitivity analyses on the LCC estimates to identify the effects of operational variables and the effects of critical study assumptions.

5) Comparing the LCC estimates for the functionally equivalent radar to the LCC estimates for the SEMR.

6) Evaluating the implications upon the LCC comparison of design changes to the SEMR conceptualized by the designing agency.

The APQ-122 (V)5 radar system was selected as the comparison radar because it is a solid-state design. It was developed as a candidate for replacing the APN-59/B systems in the C-130, C-135 and C-141 aircraft, and relevant data were available from a variety of government organizations and sources.

The formulation of the baseline LCC estimates involved the following steps:

1) Determination of the subset of APQ-122 V(5) system components which, in total, was functionally equivalent to the SEMR system configuration included in the previous LCC study.

2) Adjusting historically available APQ-122 V(5) data.

3) Structuring the input data necessary for the Generalized Electronic Maintenance Model (GEMM) computer program to compute certain logistic support cost subtotals.

Detailed descriptions of the data analysis assumptions and procedures are included in this report.

Sensitivity analyses were performed on the LCC estimates for the APQ-122 V(5) based system to assess the implications of operational variables and reliability assumptions on support cost estimates and the implications of economic escalation factors and progress curves on acquisition cost estimates.

The comparison of the LCC estimates for the two functionally equivalent configurations resulted in the following primary findings:

1) When using data collection and analysis procedures and assumptions consistent with those used in developing SEMR LCC estimates, the baseline LCC estimates for SEMR-equivalent APQ-122 systems were computed to be approximately 40 percent less than the SEMR estimates.

2) The SEMR-equivalent APQ-122 LCC estimates were found to be sensitive to the assumptions made regarding progress curve factors, economic escalation factors and system reliability estimates. However, the LCC estimates remained lower than the comparable SEMR LCC estimates over the examined ranges of these critical variables.

Because there is considerable uncertainty associated with all forecasting of future costs, these findings should not be generalized to indicate that use of standard electronic modules could not be of value to the Air Force in other applications such as simulators and limited quantity ground based electronic systems.

SECTION I

INTRODUCTION

This report is the final product of a contract research study conducted for the U. S. Air Force Avionics Laboratory by Battelle's Columbus Laboratories. A previous study conducted by Battelle analyzed the life cycle cost (LCC) characteristics of, and formulated discrete LCC estimates for the Standard Electronic Module Radar (SEMR). The results of that study were published in AFAL TR-77-25.(Reference 1)* The SEMR represents an application of the TRI-SERVICE Standard Electronic module program design concept to an Air Force Avionics mission. The purpose of the study documented in this report is to compare the SEMR LCC estimates to LCC estimates for a solid-state radar functionally similar to SEMR but designed in the convential custom sub-assembly manner. This required the following basic steps:

1) select a radar for comparison
2) formulate LCC estimates for the selected radar using consistent procedures and assumptions
3) compare the results.

The APQ-122V(5) radar system manufactured by Texas Instruments, Inc., was selected by the Battelle study team as the most comparable solid-state system for which data were accessible from Government sources.

The remainder of this section of the report includes a background discussion on the SEMR program, a review of the previous SEMR life cycle cost study, the objectives for this study, and an overview of the organization of this report.

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*Reference list is presented at the end of the main text of this report.

1.1 Background

The Tri-Service Standard Electronic Module Program (SEMP) is an outgrowth of the U.S. Navy's Standard Hardware Program (SHP) which began in the early 1960's. The SEMP represents an integrated design and logistics support concept. The SEMP design concept involves the integration of system - independent, functionally-unique standard electronic modules (SEMs) into a mission-specific system. As described in References 2 and 3, fully qualified SEMs are subject to physical and electronic interface specification and strict manufacturing quality control. The SEMP logistics concept focuses on the discard-at-failure philosophy. This concept is economically feasible for SEMs because (1) the unit cost is low and (2) the design review and quality control features of SEMP enhance the module-level reliability.

The SEMR program represents the first fabrication of an Air Force avionics system using the SEMP design concept. Under AFAL funding, the Naval Avionics Center (NAC)* designed the SEMR and fabricated two systems for environmental and flight testing. Flight testing was conducted in an NKC-135 aircraft by the 4950th Test Wing and completed in 1978. The SEMR program was a portion of a larger effort at the NAC referred to as the Modular Radar Program (MRP). A brief configuration description of the SEMR is presented later in this report. However, more comprehensive information on the MRP effort and the SEMR design can be found in References 4, 5, and 6.

In order to investigate the life cycle cost implications of the SEMP design and logistics concepts in an Air Force avionics maintenance and support environment, AFAL sponsored two independent SEMR life cycle cost studies. Parallel study contracts were issued in 1976 to Battelle's Columbus Laboratories and the Norden Division of the United Technologies Corporation. The statement of work for those studies stated the study objective as follows:

> "The objective of this program will be to provide life cycle cost data to quantify anticipated savings achieved when using Standard Electronic Modules (SEM) in Avionic equipment. The Standard Electronic Module Radar (SEMR),

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*Formerly designated the Naval Avionics Facility-Indianapolis (NAFI)

under development by AFAL as a SEM demonstration equipment, will serve as the analysis vehicle for this program. The investigations performed will provide a detailed evaluation of the impact of the SEM philosophy on equipment life cycle costs, including variations in maintenance structure, level of BITE, and throw-away vs. repair of modules." (Reference Contract #F33615-76-C-1336)

Note that the SEMR design was envisioned only as a demonstration of the SEM concept and a vehicle for the analysis of SEM life cycle cost implications. The results of the Battelle study are presented in reference 1 and are reviewed in the next section of this report. The results of the Norden study were published in reference 7.

Following the completion of the previous LCC studies, AFAL decided to fund a study which would compare the results of either of the previous studies with the LCC estimates of a functionally similar radar. Battelle was awarded this study following a competitive procurement process.

1.2 Review of Previous SEMR LCC Study Results

AFAL TR 77-25 presented an analysis of the life cycle cost characteristics of the SEMR as designed and fabricated by NAC. The study approach used by Battelle in that study focused on the implications of the SEMP concepts on Air Force avionics and used both qualitative and quantitative factors. The life cycle cost estimates for the SEMR design in three retrofit application programs were the primary quantitative results.

The conceptual retrofit programs used in structuring the SEMR LCC analysis involved replacing most of the components of the APN-59/B radar system in the following aircraft:

1) 1,900 C-130 and C-135 aircraft

2) 276 C-141 aircraft

3) 2,176 unit combined force of C-130, C-135, and C-141 aircraft. Along with quantity of aircraft equipped, life cycle cost analysis results are most sensitive to the length of operational life and the equipment utilization rates. Therefore, the basic LCC estimates for SEMR were presented in Tables 15 and 16 of AFAL TR 77-25 by showing the results of three operational life values (10,15, and 20 years)

and three use rates (low, medium, and high) for each of the three retrofit programs. The nominal values used for these parameters were 15 years of life and an historical utilization rate for each aircraft type (C-130/C-135 use rate of 1.88 hours per day, C-141 use rate of 3.07 hours per day and a weighted average of 2.07 hours per day).

Since Tables 15 and 16 in AFAL TR 77-25 represent the basic LCC estimates for the SEMR design (as fabricated by NAC), those estimates and the assumptions and procedures used in developing those estimates serve as the reference point for the comparison study documented in this report. Tables 1, 2, and 3 of this report present the SEMR LCC estimates as developed in AFAL TR 77-25 for the three retrofit applications. The baseline results, using the nominal life and use rate values, are shown as the first column in each table. The format of Tables 1, 2, and 3 is slightly different than that used in AFAL TR 77-25 and will be used for presenting the subsequent APQ-122 LCC estimates.

1.3 SEMR Comparison Study Objectives

The general objective of AFAL in sponsoring this study was, as stated in the statement of work, "to determine the impace of standard electronic modules (SEMs) upon the life cycle cost (LCC) of avionic equipment." The scope of the investigation was limited to developing LCC estimates for a radar functionally similar to the SEMR but which employs conventional design concepts and comparing the results with the previous SEMR LCC estimates.

The specific objectives established in planning this study were as follows:

1) To select a solid-state radar functionally similar to the SEMR for use in the comparative analysis
2) To collect the needed acquisition and logistics data for the comparable radar system
3) To formulate baseline LCC estimates for the comparable system using the same procedures, assumptions and life cycle cost model as used in the SEMR LCC study

TABLE 1. RESTATEMENT OF SEMR LIFE CYCLE COST ESTIMATES FOR 1900 C-130/C-135 AIRCRAFT*

(MILLIONS OF FY 77 DOLLARS)

Variables:	Baseline	Alternative Conditions				
Life (in years)	15	10	20	15	15	15
Use Rate	Nominal	Nominal	Nominal	Low	Medium	High
Cost Categories:						
Research and Development	1.916	1.916	1.916	1.916	1.916	1.916
Acquisition	137.819	137.819	137.819	137.819	137.819	137.819
Retrofit	9.263	9.263	9.263	9.263	9.263	9.263
Support Equipment	15.782	10.521	21.042	15.782	15.782	15.782
Initial Spares	18.382	18.382	18.382	17.679	18.504	24.125
Replenishment Spares	18.086	11.745	24.429	10.001	19.984	29.968
Manpower	1.281	.854	1.708	.828	1.387	1.946
Training	.645	.445	.845	.645	.645	.645
Transportation	1.142	.762	1.528	.631	1.262	1.894
Total:	204.316	191.707	216.927	194.564	206.562	223.358

*This table restates the results presented in Tables 15 and 16 of AFAL TR-77-25.

TABLE 2. RESTATEMENT OF SEMR LIFE CYCLE COST ESTIMATES FOR 276 C-141 AIRCRAFT*

(MILLIONS OF FY 77 DOLLARS)

Variables:	Baseline	Alternative Conditions				
Life (in years)	15	10	20	15	15	15
Use Rate	Nominal	Nominal	Nominal	Low	Medium	High
Cost Categories:						
Research and Development	1.916	1.916	1.916	1.916	1.916	1.916
Acquisition	24.005	24.005	24.005	24.005	24.005	24.005
Retrofit	1.029	1.029	1.029	1.029	1.029	1.029
Support Equipment	1.997	1.331	2.663	1.997	1.997	1.997
Initial Spares	2.743	2.743	2.743	2.631	2.752	3.260
Replenishment Spares	5.286	3.435	7.138	4.089	5.448	6.809
Manpower	.575	.383	.767	.506	.585	.663
Training	.165	.125	.205	.165	.165	.165
Transportation	.360	.240	.480	.278	.371	.463
Total:	38.076	35.207	40.946	36.616	38.268	40.307

*This table restates the results presented in Tables 15 and 16 of AFAL TR-77-25.

TABLE 3. RESTATEMENT OF SEMR LIFE CYCLE COST ESTIMATES FOR A 2176 UNIT COMBINED FORCE*
(MILLIONS OF FY 77 DOLLARS)

Variables:	Baseline	Alternative Conditions				
Life (in years)	15	10	20	15	15	15
Use Rate	Nominal	Nominal	Nominal	Low	Medium	High
Cost Categories:						
Research and Development	1.916	1.916	1.916	1.916	1.916	1.916
Acquisition	152.545	152.545	152.545	152.545	152.545	152.545
Retrofit	10.292	10.292	10.292	10.292	10.292	10.292
Support Equipment	15.492	10.328	20.657	15.492	15.492	15.492
Initial Spares	19.439	19.439	19.439	18.012	26.914	31.203
Replenishment Spares	22.248	14.446	30.048	10.754	32.233	53.715
Manpower	1.596	1.064	2.128	.911	2.192	3.743
Training	.645	.445	.845	.645	.645	.645
Transportation	1.513	1.009	2.017	.731	2.193	3.654
Total:	225.686	211.484	239.887	211.298	244.422	273.205

*This table restates the results presented in Tables 15 and 16 of AFAL TR-77-25.

4) To conduct a sensitivity analysis of the LCC estimate of the comparable system to identify implications of key operational parameters and critical study assumptions
5) To compare the LCC estimates for the conventionally designed radar system to the SEMR LCC estimates
6) To evaluate the implications of potential SEMR design changes conceptualized by NAC (in reference 6) upon the SEMR LCC comparison.

A final objective of the study was to document the data collected for, procedures used in, and findings of, the study in a manner which will assist AFAL in making decisions relative to the life cycle cost implications of SEMs upon avionic equipment.

1.4 Organization of This Report

This introductory section has been prepared to provide the background for the SEMR LCC comparison and state the objectives of the study. The next section of the report will briefly describe the study approach. That section will be followed by the technical discussion section. Both of these sections will sequentially address the six study objectives listed in this section. A summary of findings and conclusions will complete the main text of the report. Additional material following the main text includes a list of references, a series of appendices presenting detailed information, and a list of abbreviations and acronyms used in the report.

SECTION II

STUDY APPROACH

This section briefly describes the approach followed in performing the study tasks. Emphasis was placed throughout the performance of this study on maintaining procedural and analytical comparability with the previously developed SEMR LCC estimates.

2.1 Selection of a Comparable Radar

The primary selection criteria the radar for the LCC comparison to SEMR were established by the statement of work. These were as follows:

- the system must be functionally similar to SEMR (i.e., an airborne weather radar)
- the system must use solid-state technology
- the system design architecture must reflect the conventional line replaceable unit/shop replaceable unit (LRU/SRU) maintenance concept where the SRUs are custom assemblies and custom circuit boards.

Additional criteria used by Battelle in selecting the system for comparison included:

- similarity in program development history
- availability of data.

The APQ-122 V(5) system was selected by Battelle during the proposal stage of the study as the comparison system because:

- the system was developed as an APN-59/B replacement candidate using an LRU swap-out retrofit capability (reference 8)
- the design employs solid-state technology
- the design consists of LRU's composed of custom SRU's and the majority of the SRU's are repairable at the depot level of repair
- the system was developed under a Government contract
- it was anticipated that development, acquisition, and logistics data would be readily available.

A comparative description of the two radars is presented in the Technical Discussion section of this report.

2.2 Collection of Data

Data were collected from several sources during the study. Specific sources and types of data include:

- development costs - ASD/AE procurement files (reference 9)
- acquisition cost estimates - contractor reports (reference 10) an AFIT thesis (reference 11), and current AFLC records (reference 12)
- design reliability estimates - APQ-122 V(5) manufacturer (reference 13)
- logistics support data - AFLC logistics management systems.

These sources were used to collect information which is consistent with the types of information used in developing the SEMR LCC estimates. The detailed data is described and presented in the Technical Discussion section of this report.

2.3 Formulation of Baseline LCC Estimates

The approach to this task involved the following four steps:

1. Identification of APQ-122V(5) components in a SEMR-equivalent APQ-122 system. This was necessary because the SEMR system utilizes the APN-59/B antenna and stabilization data generator.
2. Adjustment of historical APQ-122 acquisition cost data. This involved applying a different learning curve and making an economic inflation adjustment for the different fiscal years.
3. Structuring input data for the LCC model. The collected information was prepared for the LCC model using the same procedures as were used in the SEMR LCC study. The LCC model used was the same Generalized Electronic Maintenance Model (GEMM) computer program (reference 14) used in the previous study.

4. Interpret the LCC model computer generated results. This involved adding LCC cost category subtotals to the computer output (e.g., retrofit and training) in the same manner used in the SEMR LCC study.

The detailed procedures and results of each of the above steps are presented in the Technical Discussion section.

2.4 Sensitivity Analysis of LCC Estimates

Specific LCC estimates reflect the results of many assumptions and intermediate calculations. Therefore, sensitivity of the quantitative results to key assumptions should be analyzed before drawing conclusions from any specific estimate. In this study, sensitivity analyses were performed in four areas. These analyses considered the effects of:

- varying operational parameters
- an alternative maintenance policy
- quantity-price adjustments
- economic adjustment factors.

Discussions and results of these analyses are presented in the Technical Discussion section.

2.5 Comparison of LCC Estimates

The comparison of the SEMR LCC estimates and the SEMR-equivalent APQ-122 system LCC estimates was made at three levels of aggregation. These are:

- the nine discrete cost categories as used in the previous SEMR study
- aggregation of the nine categories into three elements-acquisition costs, initial logistics costs and recurring logistics costs
- the estimated life cycle cost totals.

Results were generated in tabular and graphical format and discussed in the Technical Discussion section.

2.6 Evaluation of Conceptual SEMR Design Update

In the NAC final report for the SEMR project (reference 6) several design changes were hypothesized to reflect "lesson learned" during the fabrication and testing phases. These were reviewed by Battelle in an effort to identify any significant implications upon the LCC comparison results.

SECTION III

TECHNICAL DISCUSSION AND RESULTS

This section identifies and discusses the procedures and assumptions used in formulating SEMR-equivalent APQ-122 LCC estimates and presents the results. The material is presented in a sequential manner with each subsection building on the previous subsection. The sequence corresponds to the list of objectives in the Introduction.

3.1 Comparison of Radar System Designs

The rationale for selecting the APQ-122V(5) radar system for an LCC comparison to the SEMR is stated in the first subsection of the Study Approach Section. Although certain technical characteristics of the designs directly influence the LCC estimates, a comparison of the operating characteristics of the two systems is not within the scope of this study. It is sufficient to note that both have been flight tested in C-135 aircraft and independently compared to APN-59/B operating characteristics (references 8 and 15, respectively). In addition, operating characteristics of the APQ-122V(5) system are contained in an official Air Force Technical Order (reference 16) and a full technical description of the SEMR is contained in NAFI TR-2151 (reference 17).

The primary differences in the designs which effect life cycle costs are the differences in LRU/SRU configuration and in the associated maintenance philosophy.

In the following paragraphs, the full, operational system configurations are identified and compared and then the equivalent system configuration for the LCC analyses are identified. Subsequently, the maintenance philosophy of each system is compared.

3.1.a Physical Configuration Differences

Although both the APQ-122V(5) and SEMR systems were designed as functional replacements for the APN-59/B, they differ in LRU configuration. The APQ-122V(5) system was designed under contract to be considered as a replacement for the APN-59/B systems in operation. During the 1970-1973 time period, various organizations in the U.S. Air Force were involved in evaluating the technical and economic feasibility of replacing the APN-59/B systems with APQ-122V(5) radars (reference 11). (Ultimately, the Air Force Logistics Command opted to modify certain LRUs of the APN-59/B in lieu of replacing the entire system.) In contrast, the SEMR was designed and fabricated as only a demonstration of the SEM concept and AFAL has not advocated SEMR as a full-scale APN-59/B replacement candidate. Primarily because of the difference in program objectives, the respective designer's (Texas Instruments and NAC) chose different LRU configurations. In the APQ-122V(5) case, retrofit cost implications pressured the designers to pursue an LRU-exchange design strategy. This strategy was considered by NAC as one option among several (reference 15). However, LRU exchange requirements were not imposed on SEMR and the set was designed to permit demonstration of the built-in-test and discard-at-failure maintenance features of the SEMP design concept. This resulted in a prototype design which was not necessarily optimized for minimum life cycle cost when operated in an Air Force operational scenario.

Because the APQ-122V(5) and SEMR designers chose different LRU design strategies, it is necessary to relate both of the LRU configurations to the APN-59/B LRU configuration before a direct comparison can be made. Figure 1 presents the LRU configurations for the three radar systems. The sources of the information in Figure 1 are references 8 and 19. The APN-59/B LRU configuration is shown in the middle of figure 1. The manner in which the functions of the APN-59/B LRU's correspond to APQ-122V(5) and SEMR LRU's is shown using arrows (→), braces (}{), and equal signs (=). Where arrows meet at an equals sign the respective components are functionally equivalent. For example, the APN-59/B electronic control amplifier is shown as functionally equivalent to the APQ-122V(5) electronic control amplifier and the SEMR antenna control electronics unit. Where braces are used, the functions of several APN-59/B LRU's are grouped in one (or more) LRU in the other system. An arrow drawn directly from an APN-59/B LRU to an LRU in another system indicates that the component is identical and has been provided to the radar system as government

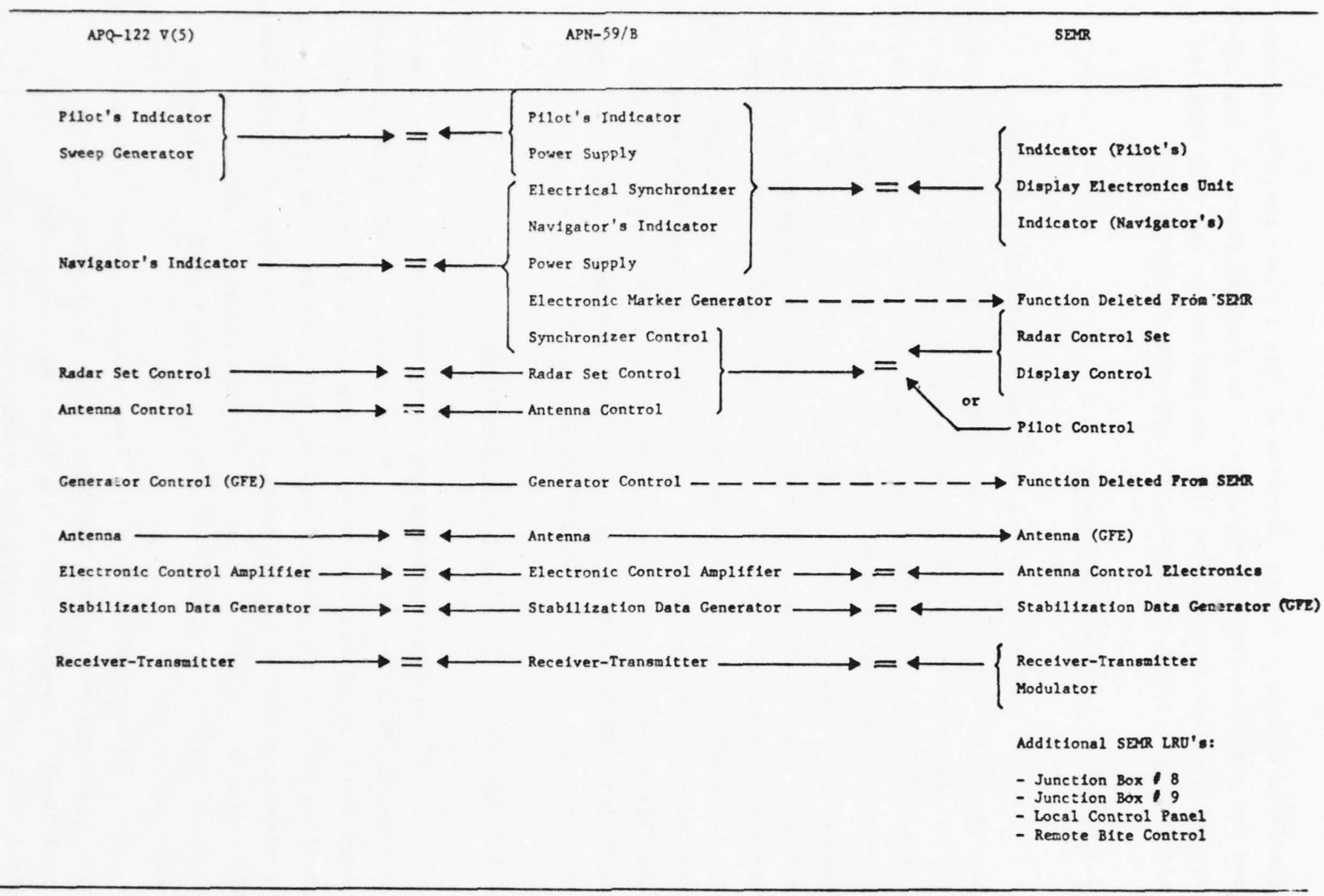

FIGURE 1. LRU CONFIGURATION COMPARISON OF RADAR SYSTEMS

furnished equipment (GFE). Examples of this include the SEMR antenna and the stabilization data generator. As shown in figure 1, two APN-59/B system functions were deleted from the SEMR design and four SEMR LRU's do not have corresponding APN-59/B (or APQ-122V(5)) LRU's.

3.1.b LCC Analysis Configurations

The SEMR LCC analysis reported in AFAL TR-77-25 did not include the government furnished antenna and stabilization data generator LRU's. In addition, two SEMR configurations were evaluated for the different aircraft to reflect a C-141 pilot operable system. During the APQ-122V(5) development time period, the C-141 configuration was essentially identical to the C-130/C-135 configuration. The APQ-122V(5) system configuration must, therefore, be modified in order to allow LCC comparisons between functionally equivalent systems. Table 4 presents the LRU configurations considered in the subsequent LCC analysis. Since the LRU configurations shown in Table 4 do not represent the complete APQ-122V(5) system, the configurations will be referred to as "SEMR equivalent APQ-122 radars" for the remainder of this report. In some instances only the term "APQ-122" will be used.

3.1.c LRU Maintenance Philosophy Comparison

The maintenance philosophy being used for the limited number of APQ-122V(5) systems in the Air Force inventory involves the standard three levels of maintenance; that is, the system is repaired by exchanging LRU's on the flight line, the LRU's are repaired at base level by exchanging SRU's, and the repairable SRU's are repaired at the depot. The number of SRU's in each LRU of the SEMR-equivalent APQ-122 is shown in Table 5. The number of SRU's discarded at failure is also shown in Table 5.

In contrast to the APQ-122 maintenance concept, the maintenance concept modeled for the SEMR LCC study involves more SRU level items (primarily SEMs) being discarded upon removal at base level. Table 6 presents the SEMR maintenance concept information

TABLE 4. LRU CONFIGURATIONS FOR SEMR-EQUIVALENT APQ-122 SYSTEMS

LRU Name	Quantity Included in: C-130/C-135 Analysis	C-141 Analysis	Combined Analysis
Electronic Control Amplifier	1900	276	2176
Receiver-Transmitter	1900	276	2176
Radar Control	1900	276	2176
Sweep Generator	1900	276	2176
Antenna Control	1900	276	2176
Pilots Indicator	1900	276	2176
Navigators Indicator	1900	0	1900

TABLE 5. MAINTENANCE PHILOSOPHY OF APQ-122 SYSTEM

LRU Name	Number of Modules Exchangeable at Base Level	Number of Exchangeable Modules Discarded Upon Removal
Electronic Control Amplifier	14	2
Receiver-Transmitter	20	3
Radar Control	3	2
Sweep Generator	14	3
Antenna Control	1	0
Pilots Indicator	9	4
Navigators Indicator	22	3
TOTAL	83	17

TABLE 6. MAINTENANCE PHILOSOPHY FOR SEMR SYSTEM

LRU Name	Number of Modules Exchangeable at Base Level	Number of Exchangeable Modules Discarded Upon Removal
Receiver-Transmitter	193	187
Modulator	3	1
Antenna Control Electronics	34	34
Display Electronics Unit	127	127
Remote Radar Control*	--	
Display Control*	--	
Local Radar Control*	--	
Remote BITE Control*	--	
Pilot Radar Control*	--	
Junction Box #8*	--	
Junction Box #9*	--	
Indicator (2)*	--	
	357	349

*These control and indicator LRUs were considered for depot repair only.

analogous to the APQ-122 information in Table 5. It should be noted that the maintenance concept used for the SEMR LCC study did not utilize the concept of fault isolation and removal of the SEMs on-board the aircraft. Such a concept would be most analogous to the U.S. Navy's shipboard maintenance practice. The removal of SEMs on-board the aircraft was considered to be infeasible in an Air Force operation because:

1) such a policy would require the flight line level supply point to manage several hundred modules in lieu of a few LRU's.
2) The majority of the failures in the receiver-transmitter would occur in the non-SEM components which would necessitate LRU removal for those failures and a dual-level strategy would be impractical, and;
3) Physical constraints in aircraft avionic bays vary and are not conducive to handling small modules in extreme weather conditions.

Additional LRU and SRU level information on the SEMR-equivalent APQ-122 system is provided later in this section. More details on the SEMR design are provided in references 1 and 17.

3.2 Data Collection Assumptions

The actual data collected for the APQ-122V(5) system and components are presented in the next subsection in support of the baseline LCC formulation. However, the nature of the cost data collected and used is important and is discussed in this subsection.

Important to the understanding of subsequent sections is an explanation of the assumptions used regarding "price" and "cost". It is assumed that to a selling organization, the difference between the "price" and the "cost to produce" a product is the fee (or profit). The fee is usally expressed as a percentage of the "cost-to-produce" and is nominally in the 8 to 15% range for defense contracting. To the buying organization, however, the "price" paid to the supplier is the same as the "cost-to-acquire". These definitions are important here because Battelle's acquisition cost estimates for the SEMR were derived using prices quoted or paid for existing or analogous hardware.* Specifically, the hardware acquisition cost estimation involved the use of quoted prices for existing, inventoried, standard electronic's modules (SEMs) and the use of prices paid for analogous hardware systems for non-SEM components. For new development SEMs, price estimates were developed using engineering judgement based on comparative analysis (complexity and componentry) with existing SEMs. Price estimates for line replaceable units consisting of SEM's were made by summing the prices of the appropriate SEMs, the mounting hardware and the discrete components and adding a 15% factor for G&A and fee for the integration effort. This relatively small G&A and fee percentage, applied to the sum, recognized the relatively high contribution to the LRU cost of the SEM's and the corresponding low contribution of the manufacturing integration effort. SEMR system level costs were then computed by summing the LRU acquisition costs (which already included the aforementioned hardware and integration "costs-to-produce" and fees).

Drawing from the approach used for the SEMR analysis, Battelle collected and used for the current study historical government data for estimating SEMR-equivalent APQ-122 development and acquisition costs. The next subsection of this report presents an outline, and then a detailed discussion, of a procedure for transforming that historical data into consistently constructed APQ-122 cost estimates. In the remainder of the report, the terms cost and acquisition costs should be interpreted as "cost-to-acquire".

Another important cost related factor is the use of economic indices to transform cost estimates from one fiscal year base to another. Costs used in the SEMR LCC study reflected an FY77 base. The primary APQ-122V(5) cost information collected for this project was dated 1971 and assumed to be based on FY72 rates. Two sources of economic indices

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* It is noted that the parallel SEMR study by NORDEN, as reported in AFAL TR-77-26, used a cost-to-produce plus fee approach to acquisition cost estimating.

were found during the data collection process.

The first source is a Headquarters, Air Force Systems Command letter dated 29 August 1978 directing the use of specific rates for all acquisition cost estimates (reference 20). Attachment 2F to that letter identified an avionics procurement index with an FY77 value of 113.49 and FY72 value of 79.45. Thus, the conversion factor from this source is 1.428 (one FY72 dollar equals 1.428 FY77 dollars).

A second source is AFR 172-10 (reference 21). This source provides an index for military procurement. Values obtainable from this source are .943 (FY77) and .645 (FY72). Use of these values would result in an FY72 to FY77 conversion factor of 1.462. However, this source also identifies other, national economy-wide indices. The wholesale price index (WPI) values for FY72 and FY77 are reported in reference 21 as .577 and .945. Use of the WPI values results in a conversion factor of 1.638.

The conversion factor value derived from the AFSC letter is used in the baseline analysis because it is the only index based strictly on avionics. However, since the procedures used assume a FY72 design to be built in FY77 dollars without an associated advance in technology (in either componentry or manufacturing technology), it could be argued that the WPI based index would be more applicable. Therefore, the effects of the conversion factor will be shown in the sensitivity analysis discussion.

3.3 Formulation of Baseline APQ-122 LCC Estimates

The LCC estimates developed in AFAL 77-25 were presented using nine cost categories. The same structure is used here. The categories are (1) research and development, (2) acquisition, (3) retrofit, (4) support equipment, (5) initial spares, (6) replenishment spares, (7) manpower (maintenance), (8) training, and (9) transportation. Subtotals for five of these categories are computed directly from data collected during this study. Each of these categories is discussed under a separate heading. The remaining category subtotals were computed using the GEMM computer program. Therefore, information and data for these categories are discussed under the heading GEMM Input Data. Thus, this section presents the data collected for, assumptions procedures, and results of the baseline SEMR-equivalent APQ-122 LCC estimate in the following subsections:

- Research and Development Costs
- Acquisition Costs
- Retrofit Costs
- Support Equipment Costs
- Training Costs
- GEMM Input Data

The baseline results are summarized for each force option at the end of this subsection.

3.3.a Research and Development Costs

In the presence of the responsible ASD contracting officer, the procurement files on the Texas Instruments contract* which covered the APQ-122 V(5) development was reviewed. In that file, the total preproduction costs for the APQ-122 V(5) system were reported as $1,837,430. This amount included engineering design and fabrication of preproduction test articles.

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*Contract number F33657-68-C-1271

Application of the economic adjustment factor (1.428) results in an estimate of $2,624 million in $FY 77.

3.3.b. Acquisition Costs

This section presents the procedures used to adjust historical APQ-122V(5) system and component cost data to SEMR-equivalent APQ-122 cost estimates in FY-77 dollars. In order to develop estimates comparable to the SEMR acquisition costs reported in AFAL TR-77-27, adjustments to historical cost data for APQ-122 V(5) radars are necessary to reflect:

- o equivalent functional systems
- o progress curve differences
- o economic escalation

Background information for these three adjustments follow.

The primary source of APQ-122 V(5) system level cost information is Table 7. The direct source of this table is reference 11 while the indirect source is a Texas Instruments submittal to the ASD program office in 1971. The cost per system for a quantity of 2000 systems in Table 7 is $49,800.

TABLE 7. APQ-122 V(5) COST DATA EXTRACTED FROM AFIT THESIS GSA/SM/73-8

Quantity	Cost Per System	Delivery of Sets Per Month
100	$71,500	15
200	64,500	20
300	63,800	25
500	58,200	25
1000	53,600	35
1500	51,700	40
1865	50,500	45
2000	49,800	50

This is the same figure that was used by TI in a published economic analysis of the APQ-122 V(5) acquisition program versus APN-59X modification program, (Reference 10). That TI analysis was thoroughly reviewed by many segments of the Air Force (AFSC and AFLC) during the 1972-73 time period. The use of the $49,800 amount by TI in Reference 10 supports the use of Table 7 in this analysis.

The information in Table 7 is for full APQ-122 V(5) systems. The definition of SEMR-equivalent APQ-122 systems was established in the previous discussion of the LRU configurations. Thus, adjusting full APQ-122 V(5) system costs to SEMR-equivalent system costs was the first adjustment necessary.

Regression analysis of the information in Table 7 indicates that the cost-quantity relationship approximates a 92% progress curve.* The SEMR estimates developed in AFAL TR-77-25 were based on a 90% progress curve. The impact of a 2% differences can be seen from the hypothetical example in Table 8. Because of the progress curve differences, it appears appropriate to adjust the quoted costs using a 90% factor. In comparing the 92% versus 90% factors, it is assumed that the value used by a bidder is more a function of manufacturing management efficiency and of competitive forces in the market place than a function of the design. The effects of the 90% assumption will be shown in the sensitivity analysis section.

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*This implies that every time the production quantity doubles the average unit price at quantity 2 decreases to 92% of the average unit price at quantity 1.

TABLE 8. HYPOTHETICAL EXAMPLE FOR PROGRESS CURVE IMPACT

First unit cost = \$200,000

Average unit cost at quantity i = first unit cost x (quantity i)$^{\ell n PC/\ell n 2}$

For progress curve values (PC) of .90 and .92 the quantity unit costs are:

Quantity	PC = .90	PC = .92	% Difference
1	200,000	200,000	--
2	180,000	184,000	+2.2
4	162,000	169,280	+4.49
100	99,317	114,932	+15.72
500	77,764	94,702	+21.78
1000	69,987	87,126	+24.49
2000	62,989	80,156	+27.25

The third adjustment to the quoted APQ-122 V(5) costs is that for economic escalation. The SEMR cost analysis was based on FY-77 dollars. To convert Fy-72 dollars to FY-77 dollars, the previously developed factor of 1.428 will be used in the baseline analysis. The effects of this factor will also be considered in the sensitivity analysis.

In summary, the procedure used to make the above adjustments to the quoted APQ-122 V(5) costs includes the following steps:

1. Determine distribution of system level adjustment factors by subtracting appropriate LRU level cost distribution factors.

2. Determine SEMR-equivalent system level adjustment factors by subtracting appropriate LRU level cost distribution factors.

3. Compute quantity-based system costs for SEMR-equivalent systems using 90% progress curve (in lieu of 92% curve used by TI)

4. Inflate quantity based system costs to FY-77 base.

5. Compute total acquisition cost for each force option.

The application of these steps to the historical data is described in detail in the following paragraphs.

3.3.b.(1) Determine APQ-122 V(5) LRU Level Cost Distribution. Data relating the distribution of the specific system level cost data in Table 7 to LRU level costs was not found in the procurement files at ASD during the procurement files review. Thus, the LRU level cost distribution was determined using data from other sources. Data from two sources were available. The first is from data previously collected from ASD/AEAC. As part of the previous SEMR LCC study, some LRU unit costs for a production buy of 36 APQ-122 V(5) systems in 1974 were obtained from the ASD/AEAC project engineer. A second source is the current LRU unit procurement costs for spares. This data is available from AFLC's DO-41 Recoverable Item Management System (Reference 12). The data available from these sources are presented in columns 1 and 3, respectively, of Table 9.

The unit costs for the stabilization data generator and pilot indicator units were not obtained from ASD/AEAC in 1976. The source file was not relocated in two visits to the ASD procurement document storage facility. However, the data in Table 9 has been used to develop LRU level distribution of system level costs by making the following assumptions and calculations:

1. Assume that the data in column 3 of Table 9 are all based on similar purchase quantities.

2. Assume that the ratio of the subtotals of the first seven rows in columns 1 and 3 is representative of the ratio of the respective system totals.

3. Use the ratio of the subtotals (158086/51743 = 3.0552) to compute the column 1 entries for the stabilization data generator and pilot's indicator from the respective entries in column 3 (i.e. 9821/3.0552 = 3212.)

4. Compute columns 2 and 4 in Table 9 by dividing each row in columns 1 and 3 by the respective totals.

5. Interpret columns 2 and 4 as LRU level cost distributions of APQ-122 V(5) system level costs.

TABLE 9. DISTRIBUTION OF LRU-LEVEL COSTS

Component	Column 1 FY-74 Cost (Q = 36)	Column 2 Distribution of Column 1	Column 3 FY-78 Cost Per Unit	Column 4 Distribution of Column 3
Antenna	14589	.2423	38522	.2094
Electronic Control Amplifier	5154	.0856	18198	.0989
Rec-Trans	14696	.2441	45315	.2463
Radar Set Control	1250	.0208	6001	.0326
Sweep Generator	4289	.0712	14917	.0811
Nav. Indicator	11401	.1893	33661	.1830
Antenna Control	364	.0060	1472	.0080
Subtotal	(51743)		(158086)	
Stab Data Gen.	3212	.0533	9821	.0533
Pilots Indicator	5261	.0874	16074	.0874
Total	60216	1.0000	183972	1.0000

Sources: Column 1. Data from ASD/AEA collected during SEMR LCC Study

Column 3. DO-41 records at Warner Robins ALC.

Note: Last two entries in column 1 are estimated from column 3 data using ratio of subtotals.

3.3.b.(2) Determine SEMR-Equivalent System Cost Adjustment Factors. The C-130/C-135 SEMR-equivalent APQ-122 system has been defined earlier as the APQ-122 V(5) system less the antenna and stabilization data generator units. Using the data in columns 2 and 4 of Table 9, two system level cost adjustment factors can be computed as follows:

1. Using column 2 of Table 9, the cost of a C-130/C-135 SEMR equivalent system is .7044 of the full APQ-122 V(5) system cost.

Where .7044 = 1 - contribution of the antenna - contribution of the stabilization data generator.
= 1. - .2423 - .0533

2. Using column 4 of Table 9, the cost of a C-130/C-135 SEMR equivalent system .7373 of the full APQ-122V(5) system cost.

   Where .7373 = 1 - .2094 - .0533

The C-141 SEMR-equivalent APQ-122 system has been defined earlier as the APQ-122V(5) system less the antenna, stabilization data generator, and navigator indicator units. In a manner similar to that presented above for the C-130/C-135 configuration, two system level cost adjustment factors can be computed:

1. Use of column 2 of Table 9 results in a computed factor of .5151.
2. Use of column 4 of Table 9 results in a computed factor of .5543.

It is assumed that since most of the data in column 1 are from the same quantity of purchase, it is more likely a better representation of the true LRU level cost distribution. Therefore, the .7044 and .5151 factors will be used in the subsequent steps in this analysis.

3.3.b.(3) Computation of Quantity Adjusted Costs for SEMR-Equivalent Systems. As discussed earlier, the quantity-cost data from TI reflects the use of a 92% progress curve. In this cost adjustment step, the combined effects of SEMR-equivalent system level cost adjustments and a 90% progress curve are computed. The results of the computations are presented in Table 10. The entries in Table 10 are in FY-72 dollars and were computed in the following manner and sequence:

1. The first row entry in column 2 (71500), is the data point from Table 7 for the quantity (100)
2. The first row entry in column 3 (36827), is the computed C-141 SEMR-equivalent APQ-122 system cost for a quantity of 100. (71500 x .5151 = 36827)
3. Calculation of the unit cost of the first unit, given a unit cost of 36827 at a quantity of 100 and a progress curve of 92%, proceeds as follows:

$$36827 = UC_1 \times (100)^{\ell n.92/\ell n2}$$

$$UC_1 = 64085$$

4. The second row, fourth column entry (27273), is the C-141 SEMR equivalent APQ-122 unit cost as computed using the above first unit cost and a 90% progress curve. The specific formulation is:

$$27273 = 64085 \times (276)^{\ell n.9/\ell n2}$$

5. The fourth row entry in column 2 (49800), is the data point from Table 7 for the quantity (2000) nearest the C-130/C-135 force quantity of 1900.

6. The fourth row entry in column 3 (35079) is the computed C-130/C-135 SEMR-equivalent APQ-122 system cost for a quantity of 2000

$$(49800 \times .7044 = 35079)$$

7. Calculation of the unit cost of the first unit, given a unit cost of 35079 at a quantity of 2000 and a progress curve of 92%, proceeds as follows:

$$35079 = UC_1 \times (2000)^{\ell n.92/\ell n2}$$

$$UC_1 = 87527$$

8. The third row, fourth column entry (27782), is the C-130/C-135 SEMR equivalent APQ-122 unit cost as computed using the above first unit cost and a 90% progress curve. The specific formulation is:

$$27782 = 87527 \times (1900)^{\ell n.9/\ell n2}$$

9. The fifth row, fourth column entry (27215), is the SEMR equivalent unit cost for a quantity of 2176 C-130/C-135 equivalent systems. The specific formulation is:

$$27215 = 87527 \times (2176)^{\ell n.9/\ell n2}$$

However, this computation includes the cost of 2176 navigation indicators while only 1900 are needed.

10. The sixth row, fourth column entry (26720) is the result of adjusting the 27215 amount computed above to delete the contribution of 276 unneeded indicators. The calculations used are as follows:

a. Navigator's indicator data:
   - o reference unit cost at quantity of 2000 = .1893 x 49800 = 9427
   - o computed first unit cost from reference point = 23522
   - o computed unit cost at quantity at 1900 (90% curve) = 7466
   - o computed unit cost at quantity of 2176 (90% curve) = 7314

b. System level adjustment:
Total cost at 2176 = 2176 x 27215 where 27215 includes 7314 for the indicator.

Adjusted total cost at 2176 = 2176 x (27215-7314) + 1900 x 7466
= 57,489,976

Average system unit cost at 2176 = 57,489,976/2176 = 26420

TABLE 10. QUANTITY COSTS FOR SEMR-EQUIVALENT SYSTEMS (FY 72 $)

Column 1 Quantity	Column 2 Quoted FY-72 Unit Cost	Column 3 Adjusted System Unit Cost	Column 4 Computed Unit Cost - FY-72
100	71500	36827	
276			27273
1900			27782
2000	49800	35079	
2176			27215 26720*

*Adjusted for only 1900 Navigators Indicators.

3.3.b.(4) Economic Escalation. The economic escalation of the data in column 4 of Table 10 represents the third adjustment of APQ-122V(5) derived cost estimates for SEMR-equivalent APQ-122 system cost estimates. All the previous data has been stated in FY 72 dollars. Development of a 1.428 factor for converting FY 72 dollars to FY 77 dollars was described earlier. Table 11 reflects the application of this escalation factor to Step 3 results.

TABLE 11. ECONOMIC ESCALATION TO $FY 77

Quantity	FY 72 Adjusted Unit Costs	Conversion Factor	FY 77 Adjusted Unit Costs
276	27273	x 1.428 =	38946
1900	27782	x 1.428 =	39673
2176	26420	x 1.428 =	37728

*Includes cost of Navigator's Indicator for 1900 units only.

3.3.b.(5) Force Level Estimates. Force-level SEMR-equivalent APQ-122 system acquisition costs are computed by multiplying Table 11 results by the appropriate quantities. The results of this multiplication are shown in Table 12.

TABLE 12. FORCE-LEVEL ACQUISITION COSTS ESTIMATES

Force Option	Quantity of Systems Required	SEMR-Equivalent APQ-122 System Cost (FY77)	Force-level Acquisition Cost (FY77)
C-130/C-135	1900	x $39,673 =	$75.379M
C-141	276	x $38,946 =	$10.749M
COMBINED	2176	x $37728 =	$82.096M

3.3.c Retrofit Costs

Retrofit costs estimates for the APQ-122 system reflect the use of existing APN-59B wiring. However, data from references 8, 10 and 11 indicate that a retrofit kit was required for the APQ-122 LRU's to attach to the APN-59B physical restraints. Therefore, retrofit costs estimates include labor and hardware costs.

References 10 and 11 estimated that 60 hours of labor would be required per aircraft for a complete APQ-122 V(5) system. This value is adjusted for SEMR equivalent systems using the previously developed .7044 and .5151 factors. A $20 per hour rate was used for retrofit labor in the SEMR LCC study and it is used in this study.

Retrofit kit cost data and estimates were adjusted in an analogous manner as the system level acquisition costs. The reference data for APQ-122V(5) retrofit kit costs is reproduced in Table 13. While this specific data were extracted from Reference 11, the same values were again found in the contractors report (Reference 10).

TABLE 13. APQ-122V(5) GROUP A INSTALLATION KIT COST DATA

Quantity	Unit Cost
100	1,489
500	1,248
1000	1,140
2000	1,046

Adjustments to Table 13 data for equivalent systems, progress curve differences and economic escalation were made using the same procedure detailed in the Acquisition Cost subsection. Table 14 summarizes the retrofit kit cost adjustments. Table 15 summarizes the retrofit costs estimates for SEMR-equivalent APQ-122 systems.

TABLE 14. ADJUSTMENTS TO REFERENCE RETROFIT KIT COSTS DATA

Quantity	Reference Costs	SEMR-Equivalent System Adjustment	Progress Curve Adjustment	Economic Escalation Adjustment
100	1489	x .5151 = 767		
276			568	x 1.428 = 811
1900			587	x 1.428 = 838
2000	1046	x .7044 = 737		
2176			575	x 1.428 = 821

TABLE 15. RETROFIT COSTS ESTIMATES FOR SEMR-EQUIVALENT APQ-122 SYSTEMS

Force Option	Quantity	Labor Computations				Kits		Total
		Hours per aircraft	Adjustment Factor	Rate 1	Subtotal (millions)	Unit Cost	Subtotal (millions)	($FY 77 Millions)
C-130/C-135	1900	60	.7044	20	1.606	838	1.592	3.198
C-141	276	60	.5151	20	.171	811	.223	.394
COMBINED	2176				1.777	821	1.786	3.563

3.3.d. Support Equipment Costs

The planned support equipment concept for the APQ-122 V(5) systems included a hot-bench mock-up at base level and a depot test set. Each base shop would therefore require an additional APQ-122 V(5) system and a test harness. Reference cost data for the test harness was again found in references 11 and 22. The adjusted estimates for the test harness unit cost in FY 77 dollars are $10,266 for the C-130/C-135 force (assumed 100 locations), $14,410 for the C-141 force (assumed at 9 locations), and $10,266 for the combined force.

Reference 22 included an estimate of $80,000 for the depot level support equipment. This equates to $114,240 in $FY 77.

The above estimates were used in preparing support equipment input data for the GEMM analysis as described in the GEMM Input subsection.

3.3.e. Training Costs

Training cost estimates for the SEMR LCC study were made available to the study contractors by AFAL. For both systems, most of the training requirements would be for base level personnel. It is assumed that training the personnel to fault isolate to the relatively few APQ-122 SRU's would be equivalent to training them to use the SEMR built in test and to fault isolate the non-SEM components.

Specific training cost estimates and assumptions in the SEMR LCC study and here are:

- o initial training set-up - $45,000
- o training of maintainenceforce - $80,000 (for C-130/C-135 and combined forces)
- o training maintenance force - $16,000 (for C-141 force)
- o turnover rate - 50% per year
- o force retraining requirements - 5 in 10 years, 7.5 in 15 years, 10 in 20 years

Thus, baseline training costs for 15 years are:

C-130/C-135 and combined = 45,000 + 7.5 x 80,000 = $645,000
C-141 = 43,000 + 7.5 x 16,000 = $165,000

Estimates for 10 and 20 year alternatives were computed in the same manner.

3.3.f. GEMM Input Data

As noted earlier, the Generalized Electronics Maintenance Model (GEMM) computer program was used to compute several of the LCC categories. A general description of the GEMM program is provided as Appendix A of this report. The principal reference for the GEMM computer program (Reference 14) provides a description of the model and serves as a user's guide for organizing input data. Information comparing GEMM to other life-cycle and logistic support cost models is also available in References 22 and 23. In the subsections of this section, the assumptions and data used in preparing input to the GEMM program are discussed. The assumptions and data in this section are detailed extensions of the system level cost data. The general approach remains that of adjusting historical data.

3.3.f.(1) Line Replaceable Unit Data. The identification of the LRU's in the SEMR-equivalent APQ-122 systems was established in Table 4. The difference between the C-130/C-135 configuration and the C-141 configuration is the deletion of the navigator's indicator in the C-141. Table 16 presents the LRU level data used in this analysis. Each column is described below.

Column 2, A and B, Table 16.

These columns reflect the distribution of the C-130/C-135 system level cost of $39,673 to the LRU's. As developed previously from Table 9, the seven LRU's represented .7044 of the full APQ-122V(5) system cost. The entries in Column 2A reflect the normalized distribution of LRU costs using system level percentages from Table 9. (Example: .0856/.7044 = .1215 for the Electronic Control Amplifier). The entries in Column 2B are the results of multiplying Column 2A by the system level cost, $39,673.

TABLE 16. LINE REPLACEABLE UNIT INPUT DATA

LRU Name	Cost Distributions and Allocations: Column 2 C130/135		Column 3 C 141		Column 4 Combined		Reliability Allocations: Column 5 TI Predicted Failure Rate,	Column 6 Distribution of Failure Rate		Column 7 LRU MTBF,	Repair Factors: Column 8 Man-Hours Per Repair		Column 9 Material Repair Costs			Weight Column 10,
Column 1	A	B ($)	A	B ($)	A	B ($)	$\times 10^{-6}$ hours	A	B	hours	A (66-1 Data)	B (Computed)	A ($)	B (hours)	C ($)	lb
Electronic Control Amplifier	.1215	4,820	.1662	6,473	.1192	4,497	288	.1182	.1677	3,472	3.9	1.55	1,681	28	1,246	29
Receiver-Transmitter	.3466	13,747	.4739	18,457	.3400	12,827	727	.2984	.4234	1,376	7.8	3.09	6,733	61	4,553	104
Radar Control	.0295	1,170	.0404	1,573	.0290	1,094	35	.0144	.0204	28,571	7.5	2.98	343	15	145	5.75
Sweep Generator	.1011	4,011	.1382	5,382	.0991	3,742	351	.1441	.2044	2,849	4.7	1.86	1,442	19	1,128	24
Antenna Control	.0085	377	.0116	452	.0083	313	10	.0041	.0058	100,000	2.2	.87	341	15	143	1.25
Pilot's Indicator	.1241	4,927	.1697	6,609	.1217	4,595	306	.1256	.1782	3,268	4.8	1.9	4,434	23	3,882	20
Navigator's Indicator	.2687	10,660	—	—	.2826	10,660	719	.2952	—	1,390	8.1	3.21	4,035	74	2,911	63
TOTAL	1.0000	39,673	1.0000	38,948	1.0000	37,728	2,436	1.0000	1.0000	410.5 (582.4)	—	—	—	—	—	247 (184)

Columns 3, A and B, Table 16.

These columns reflect the distribution of the C-141 system level cost of $38,946 computed in the same manner as Columns 2, A and B. The six LRU's have been shown to represent .5151 of the full APQ-122V(5) system. For example, the Electronic Control Amplifier represents .1662 (= .0856/.5151) of the C-141 configuration cost and the LRU cost is computed as $6,473 (=.1662 x $38,946).

Columns 4, A and B, Table 16.

As shown in Table 4, the combined forces application (C-130/C-135 and C-141) would result in procurement of 2176 units of each LRU except the navigator's indicator where 1900 would be needed. Thus, the navigator's indicator cost for Column 4 should be the same as in Column 2B. The remainder of Columns 4A and B are computed in a manner similar to Columns 2 and 3. The navigator's indicator cost of $10,660 reflects 28.25% of $37,728. Column 4A can be computed by multiplying Column 3A entries by .7175 (= 1.0 - .2825). For example, the electronic control amplifier entries become .1662 x .7175 = .1192 (4A entry) and .1192 x 37,728 = $4,497 (4B entry).

Column 5, Table 16.

The information in this column was obtained from Texas Instruments (TI) (reference 13). The data represents the predicted failure rates for the respective LRU's. TI also provided predicted failure rates for the excluded components of the APQ-122V(5) system. The TI total system failure rate was 3062 x 10^{-6} failures per hour (327 hour MTBF). This data is consistent with the reliability information used in the SEMR LCC analysis.

Column 6, A and B, Table 16.

The entries in these columns reflect the relative distribution of the system level failure rates (C-130/C-135 in Column 6A and C-141 in Column 6B) to the LRU's. It is interesting to see how closely these parallel the system level cost distribution.

Column 7, Table 16

The mean time between failure (MTBF) for each LRU is the reciprocal of the failure rate ($1/288 \times 10^{-6} = 3472$). The SEMR-equivalent system MTBF's are 410.5 and 582.4 hours, respectively, for the C-130/C-135 and C-141 systems.

Columns 8, A and B, Table 16

The GEMM model requires a system level repair time data value and a time to remove and replace each LRU. Values used in reference 1 were based on MTTR predictions. The predicted APQ-122V(5) system level repair time of .833 hours was found in reference 9. LRU predictions were not found. Therefore, data retrieved in the AFM 66-1 maintenance data collection system, and reported in the K051 data product, for the APQ-122V(5) system were used to estimate the LRU remove and replace times. The reported system level time was 2.10 hours. The reported LRU on-equipment repair times are shown in column 8A of Table 16. The reported LRU times were adjusted to a surrogate predicted value by multiplying the reported value times the ratio of the system level predicted/reported MTTR (.833/2.10=.3967). For example, for the first LRU, 3.9x.3967=1.55.

Column 9, Table 16

The data in columns 9A and B represent a depot repair cost for each LRU (Column 9A) and the depot manhours for repair (Column 9B). In order to identify repair material costs, it is necessary to subtract the labor costs out of the repair costs. Warner Robins' standard labor rate for FY78 was $12.517 per hour. Column 9C entries are computed by multiplying Column 9B entries by 12.517, subtracting the product from Column 9A entries, and dividing the remainder by 1.068 to reflect de-escalation to FY77. Example, Electronic Control Amplifier, 1246 = [1681-(28 x 12.517)]/1.068)

The manner in which LRU material repair costs are captured in GEMM is discussed later.

Column 10, Table 16

The weight of each LRU is shown in Column 10.

3.3.f.(2) Module Level Data. Development of module level data to reflect predicted reliability failure rates and large quantity procurement costs involves allocating the LRU level data from Table 16 to the repairable and discard-at-failure modules. Therefore, in Table 17, the module level data is presented in indentures style under each LRU. The LRU level data is restated where appropriate. The assumptions and procedures used in developing Table 17 entries follow.

Column 3, Table 17

The entries in this column are the module unit procurement cost data from AFLC's DO-41 (for reparable modules) and DO-62 (for discard-at-failure modules) data systems. The total of this column for each LRU is shown in parentheses on the LRU line.

Column 4. Table 17

This column reflects the distribution of the module unit costs as fractions of the Column 3 total. (For example, line 1.1 entry .1423 = 1575/11068.) Exceptions occur on lines 7.13, 7.14, and 7.21 which represent identical modules to lines 4.13, 4.11, and 4.12, respectively. For these three modules, the unit costs computed for lines 4.13, 4.11, and 4.12 are used directly in lines 7.13,

TABLE 17. MODULE LEVEL DATA

Column 1	Column 2	Column 3	Column 4	Column 5			Column 6	Column 7	Column 8	Column 9	Column 10	Column 11
				Cost Allocation			Reference					
				A	B	C	Demand	Adjusted				Average
Line Number	LRU/Module Name	Reference Unit Cost	Cost Distribution	C-130/ C-135	C-141	Combined	Rate (per 100 hours)	Failure Rate ($x10^{-6}$ hours)	MTBF	Repairability	Repair Time	Module Weight
1.0	Electronic Control Amplifier	(11,068)	(1.0000)	(4,820)	(6,473)	(4,497)	(.0533)	(268)	(3,472)	–	–	–
1.1	Roll Stabilization Amplifier	1,575	.1423	686	921	640	.0078	42	23,728	R	4	1.66
1.2	Pitch Tilt Amplifier	929	.0839	404	543	377	.0026	14	71,186	R	6	1.66
1.3	Azimuth Servoamplifier	1,537	.1389	670	899	625	.0048	26	38,559	R	6	1.66
1.4	Oscillator Servoamplifier	500	.0452	218	293	203	.0028	15	66,101	R	8	1.66
1.5	Power Supply ±5, 15, Bite	542	.0490	236	317	220	.0006	3	308,470	R	6	1.66
1.6	Power Supply ±15	813	.0734	354	475	330	.0015	8	123,388	R	6	1.66
1.7	Velocity and Loop Monitor	558	.0504	243	326	227	.0009	5	205,647	R	5	1.66
1.8	Bite Logic and Lamp Driver	685	.0619	298	401	278	.0074	40	25,011	R	13	1.66
1.9	Stabilization Gear Box Assembly	1,743	.1575	759	1,020	708	.0025	13.5	74,033	R	6	1.66
1.10	Azimuth Scanner Programmer	624	.0564	272	365	254	.0052	28	35,593	R	7	1.66
1.11	Stabilization Control Switch	519	.0469	226	303	211	.0012	6	154,235	R	[illegible]	1.66
1.12	Stabilization Control Loop Monitor	365	.0329	159	213	148	.0100	54	18,508	R	6	1.66
1.13	Tuning Assembly Motor	547	.0494	238	320	222	.0015	8	123,388	DAF	–	1.66
1.14	Lamp Test Assembly	131	.0119	57	77	54	.0045	24	41,129	DAF	–	1.66
2.0	Receiver-Transmitter	(84,650)	(1.0000)	(13,747)	(18,457)	(12,827)	(.3244)	(727)	(1,375.5)	–	–	–
2.1	Modulator	18,650	.2203	3,028	4,066	2,826	.0193	43.3	23,120	R	20	4.16
2.2	Pulse Forming Network	3,034	.0358	492	661	459	.0025	5.6	178,487	R	8	4.16
2.3	Modulator Control	1,732	.0205	282	378	263	.0181	10.6	24,653	R	7	4.16
2.4	Fault Detection and Trigger	1,278	.0151	208	279	194	.0001	.22	4,462,173	R	6	4.16
2.5	Magnetron	3,692	.0436	599	805	559	.1872	420	2,384	DAF	–	4.16
2.6	Synchronizer Assembly	1,434	.0170	234	314	218	.0080	17.9	55,777	R	7	4.16
2.7	Receiver Assembly	22,043	.2604	3,580	4,806	3,340	.0046	10.3	97,003	R	23	4.16
2.8	Waveguide Assembly	7,217	.0853	1,173	1,574	1,094	.0004	.9	1,115,543	R	7	4.16
2.9	Automatic Noise Figure Monitor	1,021	.0121	166	223	155	.0045	10.1	99,159	R	10	4.16
2.10	Modulator-Demodulator	342	.0040	55	74	51	.0150	33.6	29,748	R	6	4.16
2.11	Modulator-Subassembly	916	.0108	148	199	139	.0112	25.1	39,841	DAF	–	4.16
2.12	Power Monitor Assembly	396	.0046	63	85	59	.0105	23.5	42,497	DAF	–	4.16
2.13	IF Amplifier	4,555	.0538	740	993	690	.0139	31.2	32,102	R	11	4.16
2.14	Automatic Frequency Control	5,150	.0608	836	1,122	780	.0113	25.3	39,488	R	15	4.16
2.15	Sensitivity Time Control Generator	1,079	.0128	177	234	163	.0027	6.1	165,266	R	6	4.16
2.16	Servoamplifier Assembly	1,433	.0169	232	312	217	.0011	2.5	405,652	R	8	4.16
2.17	Bite Assembly No. 2	1,001	.0118	162	218	151	.0007	1.6	637,453	R	6	4.16
2.18	Power Supply ±20	2,652	.0313	430	578	401	.0015	3.4	297,478	R	9	4.16
2.19	Local Oscillator	6,312	.0746	1,026	1,377	957	.0097	21.8	46,002	R	15	4.16
2.20	Bite Assembly No. 1	723	.0085	117	157	109	.0021	4.7	212,484	R	6	4.16
3.0	Radar Set Control	(2,868)	(1.0000)	(1,170)	(1,573)	(1,094)	(.0605)	(35)	(28,571)	–	–	–
3.1	Tilt and Bearing Control	960	.3347	392	527	366	.0270	15.6	64,102	DAF	–	1.53
3.2	EMI Control	1,545	.5386	630	847	589	.0200	11.6	86,207	R	9	1.53
3.3	Magnetic Variation Control	363	.267	148	199	139	.0135	7.8	128,205	DAF	–	1.53

TABLE 17. (Continued)

Column 1	Column 2	Column 3	Column 4	Column 5			Column 6	Column 7	Column 8	Column 9	Column 10	Column 11
				Cost Allocation			Reference					
				A	B	C	Demand	Adjusted				Average
Line Number	LRU/Module Name	Reference Unit Cost	Cost Distribution	C-130/ C-135	C-141	Combined	Rate (per 100 hours)	Failure Rate ($x10^{-6}$ hours)	MTBF	Repairability	Repair Time	Module Weight
4.0	Sweep Generator	(11,399)	(1.0000)	(4,011)	(5,382)	(3,742)	(.1812)	(351)	(2,849)	–	–	–
4.1	Power Supply ±15	400	.0351	141	189	131	.0099	19.2	52,148	R	6	1.37
4.2	Power Supply +40	900	.0790	317	425	296	.0080	15.5	64,533	R	6	1.37
4.3	Power Supply ±5	1,117	.0980	393	527	367	.0021	4	245,839	R	7	1.37
4.4	Synchronizer Demodulator Generator	922	.0809	324	435	303	.0012	2.3	430,218	R	14	1.37
4.5	Variable Gain Amplifier	857	.0752	302	405	282	.0183	35	28,211	R	7	1.37
4.6	Sweep Integrator	1,488	.1305	523	702	488	.0500	97	10,325	R	15	1.37
4.7	Intensity Compensation Amplifier	921	.0808	324	435	302	.0037	7	139,530	R	11	1.37
4.8	Pilot's Sweep Generator Bite	690	.0605	243	326	226	.0050	9.6	103,252	R	9	1.37
4.9	Sweep Generator Mode Logic	681	.0597	239	321	224	.0200	38.7	25,813	R	7	1.37
4.10	Video Mixer-Driver	751	.0659	264	355	247	.0200	38.7	25,813	R	8	1.37
4.11	Range Mark Generator	363	.0319	128	172	119	.0250	48.4	20,650	R	4	1.37
4.12	Rate Multiplier	327	.0287	115	154	107	.0045	8.7	114,725	DAF	–	1.37
4.13	Binary Counter	1,533	.1345	540	724	503	.0045	8.7	114,725	DAF	–	1.37
4.14	Timing Generator	449	.0394	158	212	147	.0090	17.4	57,362	DAF	–	1.37
5.0	Antenna Control	(745)	(1.0)	(337)	(452)	(313)	(.0124)	(10)	(100,000)	–	–	–
5.1	Sector Width Assembly	745	1.0	337	452	313	.0124	10	100,000	R	15	1.0
6.0	Pilot's Indicator	(13,370)	(1.0000)	(4,927)	(6,609)	(4,595)	(.5313)	(306)	(3,268)	–	–	–
6.1	Front Panel Assembly	2,254	.1686	831	1,114	775	.0500	29	34,722	R	5	1.78
6.2	Deflection Amplifier Power Supply	299	.0224	110	148	103	.0020	1.1	868,056	DAF	–	1.78
6.3	DVST Signal Circuits	493	.0369	182	244	169	.0135	7.8	128,600	DAF	–	1.78
6.4	Switch Mounting Assembly	314	.0235	116	155	108	.0020	1.1	868,056	R	2	1.78
6.5	Vertical-Horizontal Amplifier	451	.0337	166	223	155	.0140	8	124,008	R	11	1.78
6.6	Yoke Driver Assembly	2,069	.1547	762	1,023	711	.1000	58	17,361	R	14	1.78
6.7	Power Supply	4,357	.3258	1,605	2,153	1,497	.1393	80	12,463	DAF	–	1.78
6.8	HVPS Oscillator	430	.0322	159	213	148	.0037	2	469,219	R	8	1.78
6.9	Tube and Yoke Assembly	2,703	.2022	996	1,336	929	.2066	119	8,403	DAF	–	1.78
7.0	Navigator's Indicator	(26,111)	(1.0000)	(10,660)	–	–	(.3989)	(719)	(1,390)	–	–	–
7.1	Power Supply Deflection Amplifier Assembly	4,503	.1885	(1,830)	–	–	.0047	8	118,072	R	19	2.29
7.2	Indicator Interface	500	.0209	203	–	–	.0118	21	47,029.	R	6	2.29
7.3	Static and Dynamic Focus	581	.0243	236	–	–	.0012	2.2	462,449	R	7	2.29
7.4	Synchronizer Demodulator Generator	745	.0312	303	–	–	.0124	22	44,753	R	15	2.29
7.5	Variable Gain Amplifier	857	.0359	348	–	–	.0183	33	30,324	R	7	2.29
7.6	Sweep Integrator	1,273	.0533	517	–	–	.0136	24	40,804	R	12	2.29
7.7	Video Amplifier	1,337	.0560	544	–	–	.0211	38	26,300	R	15	2.29
7.8	Intensity Compensation	1,488	.0623	605	–	–	.0500	90	11,099	R	15	2.29
7.9	Mode Logic	544	.0228	221	–	–	.0099	18	56,054	R	15	2.29
7.10	Delay Trigger Generator	944	.0395	383	–	–	.0200	36	27,747	R	8	2.29
7.11	Timing Generator Interface	864	.0362	351	–	–	.0500	90	11,099	R	7	2.29
7.12	Pin Cushion Correction	723	.0303	294	–	–	.0090	16	61,660	R	11	2.29
7.13	Binary Counter	1,533	–	657	–	–	.0045	8	123,320	DAF	–	2.29
7.14	Range Mark Generator	363	–	156	–	–	.0250	45	22,197	R	5	2.29
7.15	Range Cursor Generator	612	.0256	248	–	–	.0500	90.1	[illegible]	R	6	2.29
7.16	Multiplex Generator	438	.0183	178	–	–	.0500	90.1	11,099	R	5	2.29
7.17	Power Supply ±15	400	.0167	162	–	–	.0099	17.8	56,054	R	6	2.29
7.18	Power Supply ±40	1,342	.0562	546	–	–	.0040	7.2	138,734	R	11	2.29
7.19	Power Supply ±5	1,117	.0468	454	–	–	.0021	4	264,257	R	7	2.29
7.20	Panel Assembly	3,779	.1582	1,536	–	–	.0074	13	74,992	R	18	2.29
7.21	Rate Multiplier	327	–	140	–	–	.0045	8	123,320	DAF	–	2.29
7.22	Power Supply 8 KV	1,842	.0771	748	–	–	.0195	35	28,458	DAF	–	2.29

7.14, and 7.21. The sum of these reference unit costs is subtracted from the total for item 7.0 (26111-2223 = 23888) and the new total is used to determine the distribution. (For example, line 7.1 entry .1885 = 4503/23888.)

Column 5, Table 17

The entries in this column are computed by multiplying the factors in Column 4 times the LRU level cost for the C-130/C-135 case (Column 5A), the C-141 case (Column 5B), and the combined force case (Column 5C). Exceptions occur in LRU 7, where the costs are common between the first and last case are not included in the C-141 case. The module costs for lines 7,13, 7.14, and 7.21 are equal to those on lines 4.12, 4.13, and 4.11 respectively. The number in parentheses on the LRU lines is the LRU unit cost from Table 16 of this report.

Column 6, Table 17

The entries in this column are the historical demand rates per 100 hours for the modules as reported in the D041 system. It is assumed that the relative distribution of these demand rates, among an LRU, is proportional to the distribution of the predicted reliability for each module.

Column 7, Table 17

The adjusted failure rates in this column are computed by multiplying Column 6 data by the ratio of the sum of the Column 6 data over the LRU failure rate from Table 16. (For example, line 1.1 entry 42 = .0078 x [288/.0533].)

Column 8, Table 17

The entries in this column are the reciprocal of the entries in Column 7. (Note: the calculations for both Columns 7 and 8 were done in sequence using a hand calculator. Column 7 data were rounded off for reporting purposes, thus Column 8 data cannot be computed from the reported figures.)

Column 9, Table 17

Repairability of the modules are shown in this column using the code: R = repairable, DAF = discard-at-failure.

Column 10, Table 17

The repair times shown in this column were extracted from the DO-41 system.

Column 11, Table 17

The average module weight for each module was computed by subtracting 10% of the LRU weight (for a chassis) and dividing the remainder by the number of modules in the LRU.

3.3.f.(3) Part Level Input Data. The input data for the GEMM computer program is structured to capture depot level repair material costs at the piece-part level. The procedure for doing this involves identifying the cost and reliability of part classes and identifying how many units of each part class are in each SRU. If the SRU is designated by the input as being repaired at the depot level, then parts are consumed and accounted for in the replenishment spares category. For the APQ-122 analysis, the repairable SRU's were described as consisting of one part to be replaced at depot level. For the repairable SRU's in a given LRU, the cost of each hypothetical part was computed by dividing the average LRU material repair cost (column 9C, Table 16) by the number of repairable SRUs. This procedure is based on the assumption that when an LRU consisting of repairable SRUs is returned to depot, it is full of failed SRUs. The reliability figures were computed in an analogous manner. The above accounting for repair material costs may be an overstatement for the APQ-122 systems but it does capture an important segment of the support costs. The SEMR LCC analysis reflects a high replenishment spares factor due directly to the discard-at-failure policy for the SEMs. The capturing of the material repair costs for the APQ-122 is important in maintaining consistency for comparability of the analyses.

3.3.f.(4) Force Structure Deployment Data. Life cycle cost analyses are critically sensitive to the quantity and utilization of aircraft and the number of maintenance/supply organizations. The data used for these variables in the APQ-122 analysis are presented in Table 18 and are identical to the values used in the SEMR LCC study.

TABLE 18. FORCE STRUCTURE DEPLOYMENT DATA

DATA ITEM	FORCE OPTIONS		
	C-130/C-135	C-141	COMBINED
Quantity of Aircraft	1,900	276	2,176
Annual Flying Hours (Force)	859,272	257,112	1,116,384
Average Hours Per Operating Day (250 Operating Days Per Year)	1.81	3.90	2.07*
Number of Maintenance Organizations by Level:	120	9	129
Organization	120	9	129
Base	100	9	100**
Depot	1	1	1

* Weighted average of C-130/C-135 and C-141 rates.

** Base level number does not differ between the first and third option because both C-130 and C-141 forces are operated by the Military Airlift Command and the base level shops would be shared.

3.3.f.(5) Miscellaneous Input Data. Table 19 presents the logistics support input data for the GEMM program which is not design-dependent. The values shown in Table 19 are the same values used in the previous SEMR LCC study. The GEMM program can compute personnel costs on a "shared" or "dedicated" basis. "Shared" implies that only the time used repairing the item will be costed while dedicated implies that the entire salary of an integer number of personnel will be costed. The assumption for this analysis and the SEMR analysis was that the organizational and base shop level personnel would be shared and the depot personnel would be dedicated.

3.3.f.(6) GEMM Computations. The data identified in the preceding paragraphs were assembled and input into the GEMM computer program using Battelle's CDC computer systems. The program produced cost category subtotals for the support equipment initial and replenishment spares, manpower, and transportation categories.

3.3.g. Results of Baseline LCC Analyses

The results of exercising the assumptions and procedures discussed in this section and executing the GEMM program with the described data are combined in Table 20. The figures in Table 20 represent the baseline, fifteen year LCC estimates for SEMR-equivalent, APQ-122 systems in the three force options at nominal use rates. The bottom row in Table 20 presents the similarly computed LCC estimate total for the SEMR systems.

TABLE 19. LOGISTICS SUPPORT INPUT DATA

Data Item Description			Value Used
Transportation Time			
Organizational - Base			.5 hrs
Base - Depot			120 hrs
Transportation Cost			$.53/lb
Requisition Time (hrs)	Parts	Assemblies	LRU's
Organizational	120	120	240
Base	120	120	240
Depot	4	4	6
Wait Time for Repair			
Organizational			1 hr
Base			2 hrs
Depot			72 hrs
Productivity Factor			
Depot			1.
Other			.5
Safety Stock			
Sigma			1.29
Probability			.90
Reorder Period			9 months
Stockage Objective Period	Discards	Repairables	
Base	1 month	10 days	
Depot	3 months	.5 months	
Turnaround Time			
Base	4 days		
Depot	1.5 months		
Annual Personnel Cost			
Organizational	$ 7043		
Base Stage	$10149		
Depot	$18000		

TABLE 20. BASELINE LCC ESTIMATES FOR SEMR-EQUIVALENT APQ-122 SYSTEMS

(Millions of FY-77 Dollars)

	FORCE OPTIONS		
	C-130/C-135	C-141	COMBINED
Variables:			
Life (in years)	15	15	15
Use Rate	Nominal	Nominal	Nominal
Cost Categories:			
Research and Development	2.624	2.624	2.624
Acquisition	75.379	10.749	82.096
Retrofit	3.198	.394	3.563
Support Equipment	10.574	1.328	10.171
Initial Spares	10.671	1.181	10.813
Replenishment Spares	17.580	5.557	21.774
Manpower	1.184	.464	1.478
Training	.645	.165	.645
Transportation	.049	.009	.065
TOTAL:	121.904	22.471	133.229
Comparable SEMR Total:	204.316	38.076	225.686

3.4 Sensitivity Analysis of Baseline LCC Results

The quantitative results of any life cycle cost analysis reflects the combination of data from many sources and the execution of numerous mathematical computations. Multiple data sources and assumptions introduce errors which are compounded by the mathematical computations. Therefore, conclusions should not be based only on single value LCC estimates . LCC evaluations should also consider the results obtained through an series of sensitivity analyses. For this study, five sensitivity areas are important in preparing SEMR-equivalent APQ-122 LCC estimates for comparison to the SEMR LCC estimates. These five areas are as follows:

1. The effects of ranges for the operational parameters effecting length of service and equipment utilization rates.
2. The effects of a different maintenance policy, one which is similar to the SEMR discard-at-failure policy
3. The effects of MTBF degradation from predicted values
4. The effects of using a more conservative progress-curve for calculating acquisition costs
5. The effects of using a higher economic adjustment factor

The first and second areas for sensitivity analysis are basically structured in nature in that the effects will be controlled by the structure of the LCC model being used and the relationships between the equipments design and support policy. The fourth and fifth areas of sensitivity analysis each consider critical assumptions made in preparing the data for the baseline LCC estimates. The third area involves a critical assumption and is also dependant on the structure of the LCC model to capture the effects of the assumption. Results produced in each of the sensitivity analysis will be presented separately in the following subsection. The common reference points for all are the three baseline LCC estimates shown in Table 20.

3.4.a Effects of Operational Parameter Values

Two parameters important in all LCC analyses are the service life of the equipment and the utilization rate. Although these are related terms, there are distinct differences in their implications. If the LCC analyses is being performed to compare two systems and one has a lower investment cost and the other has a lower operating cost profile, the service life value is critical to the determination of a cross-over point. The key effect of the utilization rate is in the determination of spares requirements. This effect is especially important when the computational process transforms fractional requirements into the next higher integer number. The GEMM program used in this analysis does adjust fractional requirements upward.

The baseline LCC estimates presented in Table 20 were computed using a value of 15 years for projected life and a nominal utilization rate for each force based on historical records. The sensitivity effects of these parameters were determined by recomputing the estimates using 10 and 20 year life periods with the nominal utilization rate and a 15 year life period with low, medium, and high utilization rates. The low, medium and high rate values used were selected in order to bracket the nominal values and the specific values used are shown in Table 21. The results produced by these changes in the operational parameters are presented in Tables 22, 23, and 24 respectively for each force option. The implications of these results will be discussed in the comparison section.

TABLE 21. VALUES OF UTILIZATION RATES USED IN SENSITIVITY ANALYSES

Force Option	Nominal Utilization Rate (Hrs/Day)	Low Value (Hrs/Day)	Medium Value (Hrs/Day)	High Value (Hrs/Day)
C-130/C-135	1.81	1	2	3
C-141	3.88	3	4	5
Combined	2.07	1	3	5

TABLE 22. LIFE CYCLE COST ESTIMATES FOR SEMR-EQUIVALENT APQ-122 RADARS IN 1900 C-130/C-135 AIRCRAFT
(MILLIONS OF FY 77 DOLLARS)

MAINTENANCE POLICY: STANDARD

Variables:	Baseline	Alternative Conditions				
Life (in years) Use Rate	15 Nominal	10 Nominal	20 Nominal	15 Low	15 Medium	15 High
Cost Categories:						
Research and Development	2.624	2.624	2.624	2.624	2.624	2.624
Acquisition	75.379	75.379	75.379	75.379	75.379	75.379
Retrofit	3.198	3.198	3.198	3.198	3.198	3.198
Support Equipment	10.574	7.049	14.099	10.574	10.574	10.911
Initial Spares	10.671	10.671	10.671	10.084	10.796	11.440
Replenishment Spares	17.580	11.413	23.743	9.718	19.423	29.130
Manpower	1.184	.789	1.579	.775	1.280	2.055
Training	.645	.445	.845	.645	.645	.645
Transportation	.049	.033	.065	.027	.054	.081
Total:	121.904	111.601	132.203	113.024	123.973	135.463
Comparable SEMR Total:	204.316	191.707	216.927	194.564	206.562	223.358

TABLE 23. LIFE CYCLE COST ESTIMATES FOR SEMR-EQUIVALENT APQ-122 RADARS IN 276 C-141 AIRCRAFT

(MILLIONS OF FY 77 DOLLARS)

MAINTENANCE POLICY: STANDARD

Variables:	Baseline	Alternative Conditions				
Life (in years)	15	10	20	15	15	15
Use Rate	Nominal	Nominal	Nominal	Low	Medium	High
Cost Categories:						
Research and Development	2.624	2.624	2.624	2.624	2.624	2.624
Acquisition	10.749	10.749	10.749	10.749	10.749	10.749
Retrofit	.394	.394	.394	.394	.394	.394
Support Equipment	1.328	.885	1.771	1.328	1.328	1.328
Initial Spares	1.181	1.181	1.181	1.093	1.202	1.467
Replenishment Spares	5.557	3.609	7.502	4.297	5.727	7.160
Manpower	.464	.310	.619	.420	.470	.520
Training	.165	.125	.205	.165	.165	.165
Transportation	.009	.006	.012	.007	.009	.011
Total:	22.471	19.883	25.057	21.077	22.668	24.418
Comparable SEMR Total:	38.076	35.207	40.467	36.616	38.268	40.307

TABLE 24. LIFE CYCLE COST ESTIMATES FOR SEMR-EQUIVALENT APQ-122 RADARS IN A 2176 UNIT COMBINED FORCE (MILLIONS OF FY 77 DOLLARS)

MAINTENANCE POLICY: STANDARD

Variables:	Baseline	Alternative Conditions				
Life (in years)	15	10	20	15	15	15
Use Rate	Nominal	Nominal	Nominal	Low	Medium	High
Cost Categories:						
Research and Development	2.624	2.624	2.624	2.624	2.624	2.624
Acquisition	82.096	82.096	82.096	82.096	82.096	82.096
Retrofit	3.563	3.563	3.563	3.563	3.563	3.563
Support Equipment	10.171	6.781	13.561	10.171	10.504	10.836
Initial Spares	10.813	10.813	10.813	10.002	11.463	13.102
Replenishment Spares	21.774	14.141	29.413	10.526	31.556	52.585
Manpower	1.478	.985	1.970	.853	2.290	3.723
Training	.645	.445	.845	.645	.645	.645
Transportation	.065	.043	.086	.031	.094	.157
Total:	133.229	121.491	144.971	120.511	144.835	169.331
Comparable SEMR Total:	225.686	211.484	239.887	211.298	244.422	273.205

3.4.b Effects of Discard Maintenance Policy

As described previously, the maintenance policy for the APQ-122 V(5) system is the standard Air Force policy (i. e. fault isolation and exchange of an SRU at base level and SRU repair at the depot). Because the SEMP logistics concept is based on SRU discard-at-failure, it was considered important to test a discard policy on the SEMR-equivalent system. Two reasons for this were to provide assurances that the GEMM program did not structurally penalize discard concepts and to verify the assumed optimality of the SRU repair policy.

The effects of a discard policy on the SEMR-equivalent APQ-122 systems LCC estimates were determined by changing the maintenance policy input data from the GEMM program. The baseline results were computed and the operational parameters were again varied. The results are presented in the same format as the previous tables in Tables 25, 26, and 27. As can be seen by comparing Tables 22, 23, and 24 with Tables 25, 26, and 27, respectively,the discard policy reduces support equipment (none required at depot level), manpower (none required at depot level), and transportation (no maintenance shipments to and from depot required)*. The trade-offs to these reductions are the increases in the initial and replenishment spares costs.

The results of the discard policy do indicate a slight cost reduction in some cases. However, the primary result of this sensitivity test should be the interpretation that no structural penalty is imposed on the discard policy by the GEMM program.

3.4.c. Effects of Reliability Degradation

The SEMR -equivalent APQ-122 LCC estimates presented previously in this report have been computed using the predicted system MTBF values. This was done to maintain consistency with the previous SEMR LCC study. However, avionic systems have

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*As noted in Appendix A, the GEMM program computes only the transportation costs associated with maintenance. It does not capture the original distribution costs.

TABLE 25. LIFE CYCLE COST ESTIMATES FOR SEMR-EQUIVALENT APQ-122 RADARS IN 1900 C-130/C-135 AIRCRAFT (MILLIONS OF FY 77 DOLLARS)

MAINTENANCE POLICY: THROWAWAY

Variables:	Baseline	Alternative Conditions				
Life (in years)	15	10	20	15	15	15
Use Rate	Nominal	Nominal	Nominal	Low	Medium	High
Cost Categories:						
Research and Development	2.624	2.624	2.624	2.624	2.624	2.624
Acquisition	75.379	75.379	75.379	75.379	75.379	75.379
Retrofit	3.198	3.198	3.198	3.198	3.198	3.198
Support Equipment	10.238	6.825	13.650	10.238	10.238	10.238
Initial Spares	13.579	13.579	13.579	13.128	13.670	14.152
Replenishment Spares	16.602	10.786	22.420	9.182	18.345	27.502
Manpower	.914	.609	1.219	.505	1.010	1.515
Training	.645	.445	.845	.645	.645	.645
Transportation	--	--	--	---	--	--
Total:	123.179	113.445	132.914	114.899	125.109	135.253
Comparable SEMR Total:	204.316	191.707	216.927	194.564	206.562	223.358

TABLE 26. LIFE CYCLE COST ESTIMATES FOR SEMR-EQUIVALENT APQ-122 RADARS IN 276 C-141 AIRCRAFT

(MILLIONS OF FY 77 DOLLARS)

MAINTENANCE POLICY: THROWAWAY

Variables:	Baseline	Alternative Conditions				
Life (in years)	15	10	20	15	15	15
Use Rate	Nominal	Nominal	Nominal	Low	Medium	High
Cost Categories:						
Research and Development	2.624	2.624	2.624	2.624	2.624	2.624
Acquisition	10.749	10.749	10.749	10.749	10.749	10.749
Retrofit	.394	.394	.394	.394	.394	.394
Support Equipment	.984	.656	1.313	.984	.984	.984
Initial Spares	1.356	1.356	1.356	1.290	1.377	1.625
Replenishment Spares	5.656	3.620	7.512	4.309	5.736	7.163
Manpower	.194	.130	.259	.150	.200	.251
Training	.165	.125	.205	.165	.165	.165
Transportation	--	--	--	--	--	--
Total:	22.122	19.654	24.412	20.665	22.229	23.955
Comparable SEMR Total:	38.076	35.207	40.467	36.616	38.268	40.307

TABLE 27. LIFE CYCLE COST ESTIMATES FOR SEMR-EQUIVALENT APQ-122 RADARS IN A 2176 UNIT COMBINED FORCE
(MILLIONS OF FY 77 DOLLARS)

MAINTENANCE POLICY: THROWAWAY

Variables:	Baseline	Alternative Conditions				
Life (in years)	15	10	20	15	15	15
Use Rate	Nominal	Nominal	Nominal	Low	Medium	High
Cost Categories:						
Research and Development	2.624	2.624	2.624	2.624	2.624	2.624
Acquisition	82.096	82.096	82.096	82.096	82.096	82.096
Retrofit	3.563	3.563	3.563	3.563	3.563	3.563
Support Equipment	9.839	6.559	13.118	9.839	9.839	9.939
Initial Spares	13.498	13.498	13.498	12.880	14.006	15.112
Replenishment Spares	20.805	13.512	28.099	10.061	30.145	50.230
Manpower	1.208	.805	1.610	.583	1.750	2.917
Training	.645	.445	.845	.645	.645	.645
Transportation	--	--	--	--	--	--
Total:	134.251	123.075	145.426	122.264	144.641	166.999
Comparable SEMR Total:	225.686	211.484	239.887	211.298	244.422	273.205

historically suffered severe reliability degradation in operational use. Typically, MTBF values of one-half to one-fifth of the predicted values are observed. There are many reasons for this degradation (see Reference 4). Whatever the reason, however, the major effect is higher support costs. The effects of reliability degradation on the SEMR-equivalent APQ-122 LCC estimates were computed by multiplying the system, LRU, SRU, and part level MTBF's by .5 and .2, and inputing the changed data into the GEMM program. All other data values for the baseline analyses were held constant. The results obtained are presented in Tables 28, 29, and 30 for each force option, respectively. The implications of these results are discussed in the subsequent comparison section.

3.4.d. Effects of the Progress Curve Assumption

As discussed in the formulation of SEMR-equivalent APQ-122 acquisition cost estimates, historical APQ-122V(5) estimates were recomputed to reflect a 90% progress curve. This was done to be consistent with the previous SEMR analysis. The effects of the more conservative 92% progress curve can be approximated by multiplying the subtotals of the affected cost categories times the progress curve factor ratios as developed in Table 31. The primary categories affected include: acquisition, retrofit, support equipment, and spares. The results of applying the factor ratio are shown in Table 32. The labor portion of retrofit is insensitive to the difference but, for simplicity, is not segregated in this analysis.

The implications of these results are discussed in the comparison section.

TABLE 31. PROGRESS CURVE FACTORS AT SPECIFIC QUANTITIES

Values for Q	Q .90/ 2	Q .92/ 2	Progress Curve Factor Ratio f(.92)/f(.90)
276	.4356	.5086	1.195
1900	.3174	.4033	1.2075
2176	.3109	.3967	1.2759

TABLE 28. EFFECTS OF RELIABILITY DEGRADATION ON SEMR-EQUIVALENT APQ-122 LCC ESTIMATES FOR 1900 C-130/C-135 AIRCRAFT

(Millions of FY-77 Dollars)

	Alternative Conditions		
	Predicted MTBF	.5xMTBF	.2XMTBF
Cost Categories:			
Research and Development	2.624	2.624	2.624
Acquisition	75.379	75.379	75.379
Retrofit	3.198	3.198	3.198
Support Equipment	10.574	10.911	11.588
Initial Spares	10.671	11.499	14.858
Replenishment Spares	17.580	29.469	73.646
Manpower	1.184	2.368	5.638
Training	.654	.654	.645
Transportation	.049	.113	.273
TOTAL:	121.904	136.206	187.849
Comparable SEMR Total:	204.316		

TABLE 29. EFFECTS OF RELIABILITY DEGRADATION ON SEMR-EQUIVALENT APQ-122 LCC ESTIMATES FOR 276 C-141 AIRCRAFT

(Millions of FY-77 Dollars)

	Alternative Conditions		
	Predicted MTBF	.5XMTBF	.2XMTBF
Cost Categories:			
Research and Development	2.624	2.624	2.624
Acquisition	10.749	10.749	10.749
Retrofit	.394	.394	.394
Support Equipment	1.328	1.328	1.328
Initial Spares	1.181	1.654	3.062
Replenishment Spares	5.557	8.704	21.738
Manpower	.464	.659	1.238
Training	.165	.165	.165
Transportation	.009	.022	.051
TOTAL:	22.471	26.299	41.349
Comparable SEMR Total:	38.076		

TABLE 30. EFFECTS OF RELIABILITY DEGRADATION ON SEMR-EQUIVALENT APQ-122 LCC ESTIMATES FOR A 2176 UNIT COMBINED FORCE

(Millions of FY-77 Dollars)

	Alternative Conditions		
	Predicted MTBF	.5XMTBF	.2XMTBF
Cost Categories:			
Research and Development	2.624	2.624	2.624
Acquisition	82.096	82.096	82.096
Retrofit	3.563	3.563	3.563
Support Equipment	10.171	10.504	11.501
Initial Spares	10.813	11.867	19.419
Replenishment Spares	21.774	36.525	91.292
Manpower	1.478	2.955	7.371
Training	.645	.150	.362
Transportation	.065	.065	.065
TOTAL:	133.229	150.349	218.293
Comparable SEMR Total:	225.686		

TABLE 32. PROGRESS CURVE EFFECTS ON SEMR-EQUIVALENT APQ-122 BASELINE LCC ESTIMATES

(Millions of FY-77 Dollars)

	C-130/C-135		C-141		COMBINED FORCE	
	Baseline *	Adjusted**	Baseline	Adjusted	Baseline	Adjusted
Cost Categories:						
Research and Development	2.624	2.624	2.624	2.624	2.624	2.624
Acquisition	75.379	95.769	10.749	12.845	82.096	104.746
Retrofit	3.198	4.063	.394	.471	3.563	4.546
Support Equipment	10.574	13.434	1.328	1.587	10.171	12.977
Inital Spares	10.671	13.558	1.181	1.411	10.813	13.796
Replenishment Spares	17.580	22.335	5.557	6.641	21.774	27.781
Manpower	1.184	1.184	.464	.464	1.478	1.478
Training	.645	.645	.165	.165	.645	.645
Transportation	.049	.049	.009	.009	.065	.065
TOTAL:	121.904	153.661	22.471	26.217	133.229	168.658
Comparable SEMR TOTAL:	204.316		38.076		225.686	

* Baseline values computed using a 90% progress curve
** Adjusted values reflect a 92% progress curve and were computed using Table 3.1 ratios.

TABLE 33. ECONOMIC ESCALATION EFFECTS ON SEMR EQUIVALENT APQ-122 BASELINE LCC ESTIMATES

(Millions of FY-77 Dollars)

	C-130/C-135		C-141		COMBINED FORCE	
	Baseline	Adjusted**	Baseline	Adjusted	Baseline	Adjusted
Cost Categories:						
Research and Development	2.624	3.010	2.624	3.010	2.624	3.010
Acquisition	75.379	86.460	10.749	12.329	82.096	94.164
Retrofit	3.198	3.668	.394	.452	3.563	4.087
Support Equipment	10.574	12.128	1.328	1.523	10.171	11.666
Initial Spares	10.671	12.240	1.181	1.355	10.813	12.403
Replenishment Spares	17.580	20.164	5.557	6.374	21.774	24.975
Manpower	1.184	1.184	.464	.464	1.478	1.478
Training	.645	.645	.165	.165	.645	.645
Transportation	.049	.049	.009	.009	.065	.065
TOTAL:	121.904	139.548	22.471	25.681	133.229	152.493
Comparable SEMR TOTAL:	204.316		38.076		225.686	

* Baseline values computed using a FY-72 to FY-77 factor of 1.428

** Adjusted values, as appropriate, computed to reflect a 1.638 factor by multiplying baseline values by 1.147 (1.638) 1.428

3.4.e. Effects of the Economic Parameter

The primary data source for APQ-122V(5) costs was, as described earlier, dated in 1971 and assumed to be stated in FY-72 base dollars. The SEMR LCC analysis was performed using FY-77 base dollars and an economic escalation factor of 1.428 has been used to convert the FY-72 base dollars to FY-77 base dollars. In the previous escalation factor discussion, rationale for a higher factor value of 1.638 was presented. The implication of this higher value can be computed by multiplying the subtotals of the affected cost categories by a factor of 1.147 (ratio of 1.638 to 1.428). The affected cost categories are all the categories except the manpower, training, and transportation categories. The results of using the higher factor are presented in Table 33. The implications of these results are discussed in the comparison discussion.

3.5 Comparison of LCC Estimates

The pupose of this section is to present a comparison of the baseline LCC estimates for the SEMR and the SEMR-equivalent APQ-122 system and to present and discuss the implications of the sensitivity analysis, described previously upon the comparison.

3.5.a Baseline Comparison

The baseline LCC estimates from the SEMR study (Reference 1) were restated in Tables 1, 2, and 3 of this report. The baseline LCC estimates for the SEMR equivalent APQ-122 systems in the three force options were presented in Table 20. Each table presenting APQ-122 LCC estimates includes the comparable SEMR total at the bottom for immediate comparison. Table 34 summarizes the comparison of the baseline estimated LCC totals for the two systems. The baseline comparisons show the LCC estimates for the SEMR-equivalent APQ-122 systems to be approximately 41% lower than the SEMR LCC estimates. In order to visualize where the significant differences occur, figures 2, 3, and 4 show the comparative distribution of the LCC estimates among eight categories in bar graph form. The category subtotals in Figures 2, 3, and 4

TABLE 34. COMPARISON OF BASELINE LCC TOTALS

(Millions of FY77 Dollars)

	SEMR LCC Total	SEMR-Equivalent APQ-122 LCC Total	Difference	Differences as a Percent of SEMR Total
Force Option:				
C-130/C-135	204.316	121.904	82.412	40.3%
C-141	38.076	22.471	15.605	41.0%
Combined	225.686	133.229	92.457	41.0%

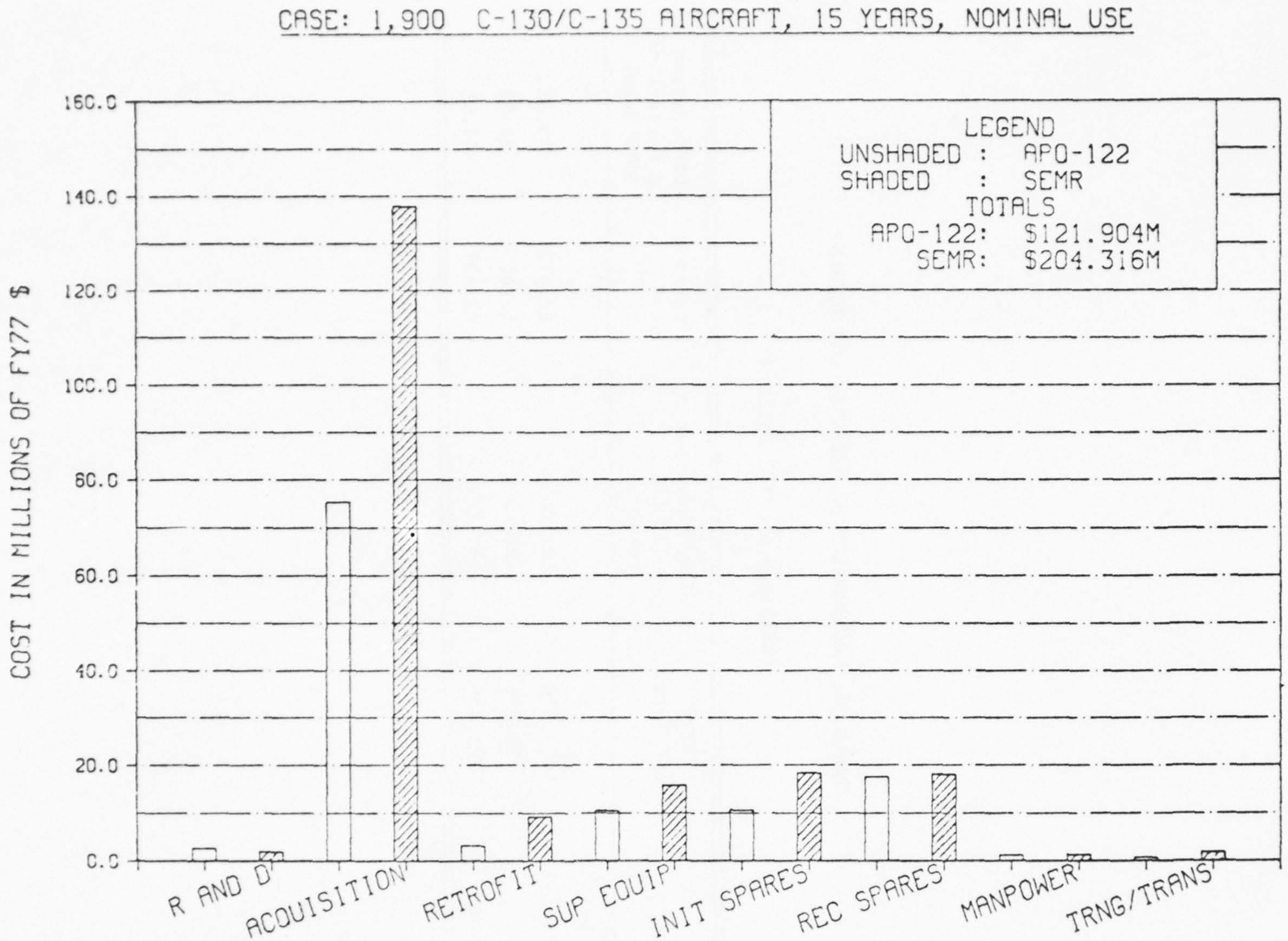


FIGURE 2. COMPARATIVE DISTRIBUTION OF LCC ESTIMATES

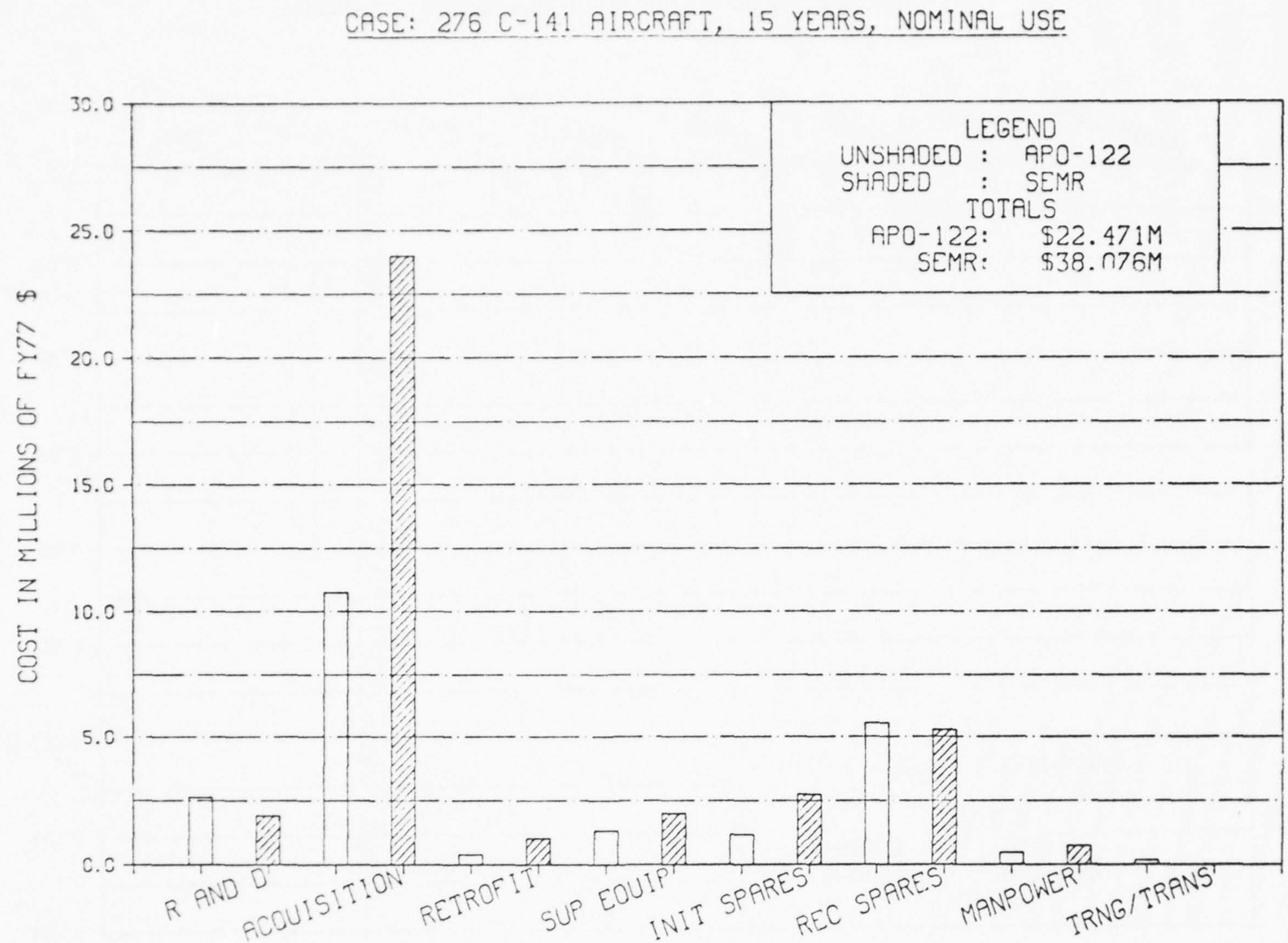


FIGURE 3. COMPARATIVE DISTRIBUTION OF LCC ESTIMATES

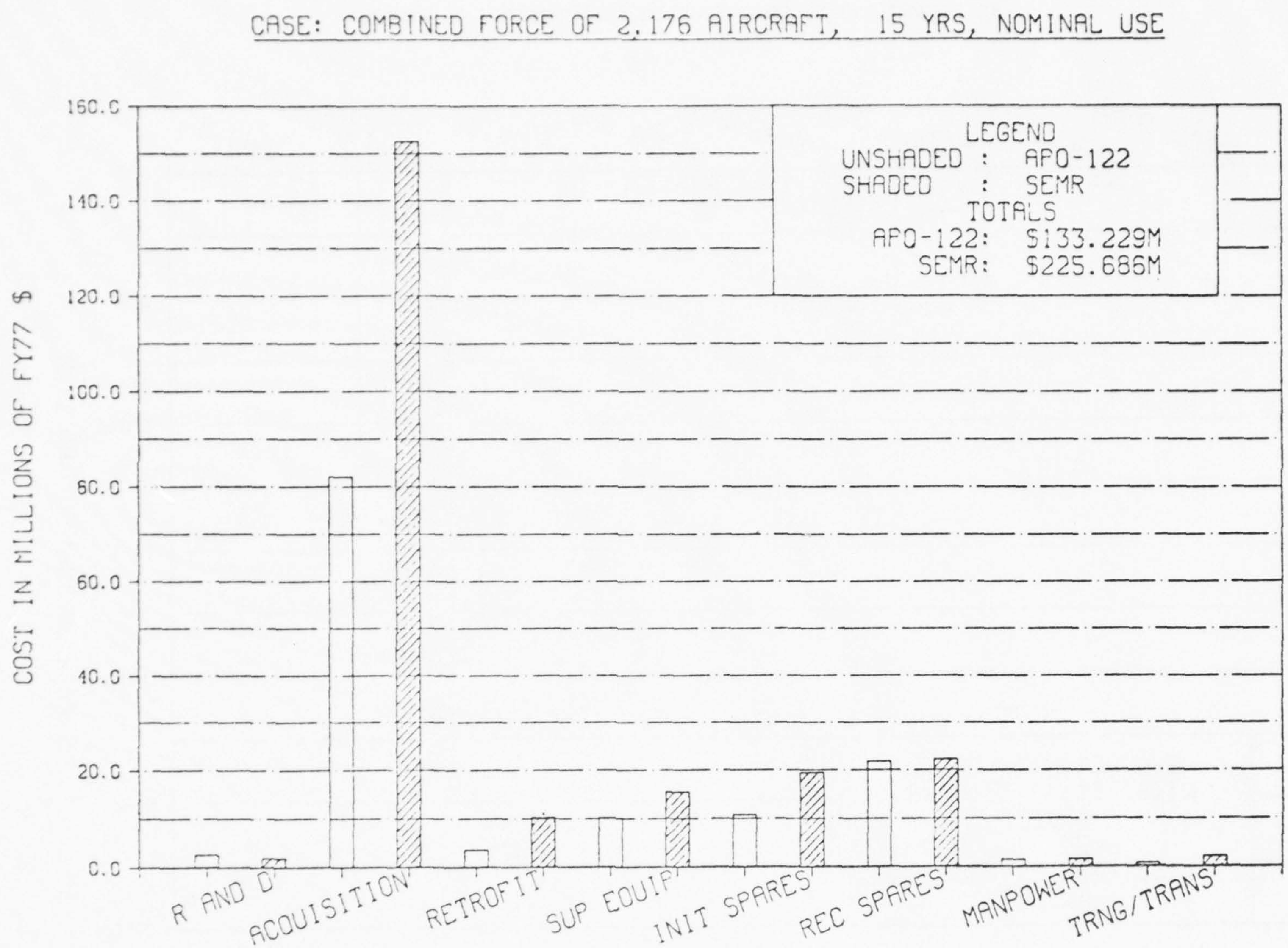


FIGURE 4. COMPARATIVE DISTRIBUTION OF LCC ESTIMATES

correspond to the detailed baseline estimates with the exception of the last category which combines the relatively small training and transportation categories (TRNG/TRANS.) It should be noted that the vertical scale for Figure 3, the C-141 case, is different than for Figures 2 and 4.

The most notable characteristic of Figures 2, 3, and 4, is that the acquisition cost is the dominant category in each LCC estimate. In addition, the SEMR acquisition cost estimate is the single most dominant factor in each LCC distribution comparison. APQ-122 category subtotals exceed the respective SEMR subcategory is some cases but these slight increases do not approach in size the large difference in the acquisition category.

Although Figures 2, 3, and 4 present the information using the cost categories used in the previous tables of this report, another type of cost segmentation is useful in comparing the systems. After the acquisition of a system, it is the total cost of the support that is of interest, not just the subtotals of the various categories. A logical approach to assessing the impact of the different design concepts upon the total support costs is, therefore, to segment the last six categories in Figures 2, 3, and 4 into two subsets: initial logistics costs and recurring logistics costs. To do this, three subsets of the cost categories are defined as follows:

- Acquisition costs include the research and development cost category and the acquisition cost category.
- Initial logistics costs are those which are incurred to install the systems and to provide a support structure. For purposes of this discussion, initial logistics costs will be defined as consisting of:
  1) retrofit costs
  2) initial support equipment costs
  3) initial spares costs

  where the retrofit and initial spares contributions are the respective subtotals already identified and the initial support equipment costs are derived from the support equipment category.

o <u>Recurring logistics costs</u> are those costs which are incurred as a result of operating and maintaining the system. For purposes of this discussion, recurring logistics costs will be defined as consisting of:

1) recurring support equipment costs
2) recurring spares
3) manpower
4) training/transportation

where recurring support equipment costs are the remainder of the support equipment costs after initial costs were subtracted and the other subtotals are as already identified.

Table 35 presents the baseline LCC estimates segmented into the three cost segments defined above. Additional observations obtained by segmenting the costs in this manner include:

1. The SEMR results do indicate a percentage distribution shift which reduces the percentage contribution of the logistics support total (initial plus recurring logistics). This shift is one of the purported benefits of the SEMR concept (Reference 2).
2. The SEMR results also indicate a percentage distribution shift between the initial and the recurring logistics costs which reduces the contribution of the recurring logistics segment.
3. Although the above observations indicate a comparative shifts for the current comparison analysis do not overcome the significant acquisition cost differences. All three categories are directly affected by the acquisition cost estimates.

The sensitivity analyses discussed below will address, the implications of the SEMR-equivalent APQ-122 LCC sensitivity analyses upon the above baseline comparisons and observations.

TABLE 35. COMPARISON OF BASELINE LCC ESTIMATES USING THREE-COST SEGMENTS

(Millions of FY 77 Dollars)

	LCC Distribution		Percentage Distribution	
	SEM	SEMR-Equivalent APQ-122 System	SEMR	SEMR-Equivalent APQ-122 System
C-130/C-135				
Acquisition	139.735	78.012	68.4	64.0
Initial Logistics	35.344	19.027	17.3	15.6
Recurring Logistics	29.237	24.874	14.3	20.4
Totals	204.316	121.913	100.0	100.0
C-141				
Acquisition	25.921	13.373	68.1	59.5
Initial Logistics	4.746	2.223	12.5	9.9
Recurring Logistics	7.409	6.875	19.4	30.6
Totals	38.076	22.471	100.0	100.0
Combined Force				
Acquisition	154.461	81.778	68.4	62.8
Initial Logistics	37.288	19.337	16.6	14.8
Recurring Logistics	33.937	29.172	15.0	22.4
Totals	225.686	130.287	100.0	100.0

3.5.b. Implications of Sensitivity Analyses

Each of the five areas of the SEMR-equivalent APQ-122 LCC estimates subjected to sensitivity analysis are discussed below. It is the implication of each of the sensitivity analyses upon the above baseline comparison which is of interest.

3.5.c. Implications of Operational Parameter Variables

The effects of changing operational life periods and operational utilization rates on the SEMR LCC estimates are presented in Tables 1, 2, and 3. The effects of the same variables on the SEMR-equivalent APQ-122 LCC estimates are presented in Tables 22, 23 and 24. For comparison purposes, the results shown in these six tables were re-distributed into the three cost segments discussed previously (acquisition, initial logistics and recurring logistics) and are tabulated in Tables 36 and 37. In turn, Tables 36 and 37 have been used to generate Figures 5, 6, and 7. The top chart in Figures 5, 6, and 7, presents the summary of the operational parameter sensitivity analysis on the SEMR LCC estimates for each force option. For comparison, the bottom chart in each figure presents the SEMR-equivalent APQ-122 LCC summary.

The results in Tables 36 and 37 and Figures 5, 6, and 7 support the findings of the baseline comparison. The SEMR LCC totals remain much higher over the ranges of values considered. It can be shown, however, that the SEMR-equivalent APQ-122 LCC estimates are slightly more sensitive to operational parameter changes. This fact is addressed in the following paragraphs.

In order to identify the comparative LCC sensitivity to operational parameters, a common reference scale must be defined. For this analysis, the ratio of the total life-time operating hours for each case to the baseline total life time operating hours was selected for the reference scale. Table 38 presents the factors used in developing baseline total operational hours and the ratio factors for the five alternative cases. Next, the ratio of the LCC total to the baseline LCC total for each sensitivity case was computed. The LCC ratios were

TABLE 36. SEMR OPERATIONAL PARAMETER SENSITIVITY RESULTS RESTATED USING THREE COST SEGMENTS

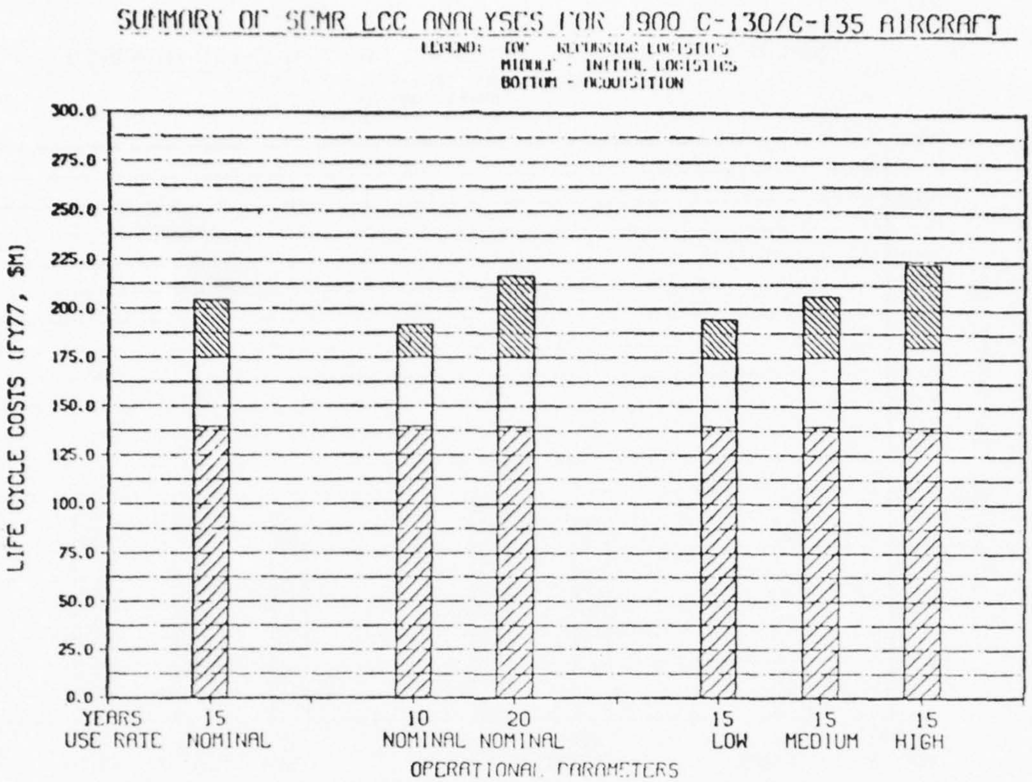
(Millions of FY 77 Dollars)

Variables:	Baseline	Alternative Conditions				
Life (years)	15	10	20	15	15	15
Use Rate	Nominal	Nominal	Nominal	Low	Medium	High
C-130/C-135						
Acquisition	139.735	139.735	139.735	139.735	139.735	139.735
Initial Logistics	35.344	35.344	35.344	34.641	35.466	41.086
Recurring Logistics	29.237	16.628	41.848	20.188	31.361	42.536
Total	204.316	191.707	216.927	194.564	206.562	223.358
C-141						
Acquisition	25.921	25.921	25.921	25.921	25.921	25.921
Initial Logistics	4.746	4.746	4.746	4.634	4.755	5.263
Recurring Logistics	7.409	4.540	10.279	6.061	7.592	9.123
Total	38.706	35.207	40.946	36.616	38.268	40.307
Combined Force						
Acquisition	154.461	154.461	154.461	154.461	154.461	154.461
Initial Logistics	37.288	37.288	37.288	35.861	44.763	49.052
Recurring Logistics	33.937	19.735	48.138	20.976	45.198	69.692
Total	225.686	211.484	239.887	21[illegible].298	244.422	273.205

TABLE 37. SEMR EQUIVALENT APQ-122 OPERATIONAL PARAMETER SENSITIVITY RESULTS RESTATED USING THREE COST SEGMENTS

(Millions of FY 77 Dollars)

Variables:	Baseline	Alternative Conditions				
Life (years)	15	10	20	15	15	15
Use Rate	Nominal	Nominal	Nominal	Low	Medium	High
C-130/C-135						
Acquisition	78.012	78.012	78.012	78.012	78.012	78.012
Initial Logistics	19.027	19.027	19.027	18.440	19.152	19.960
Recurring Logistics	24.874	14.571	35.173	16.581	26.818	37.500
Total	121.913	111.610	132.212	113.033	123.982	135.472
C-141						
Acquisition	13.373	13.373	13.373	13.373	13.373	13.373
Initial Logistics	2.223	2.223	2.223	2.135	2.244	2.509
Recurring Logistics	6.875	4.287	9.461	5.569	7.051	8.536
Total	22.471	19.883	25.057	21.077	22.668	24.418
Combined Force						
Acquisition	81.778	81.778	81.778	81.778	81.778	81.778
Initial Logistics	19.337	19.337	19.337	18.526	19.987	21.626
Recurring Logistics	29.172	17.434	40.914	17.265	40.128	62.985
Total	130.287	118.549	142.029	117.569	141.893	166.389



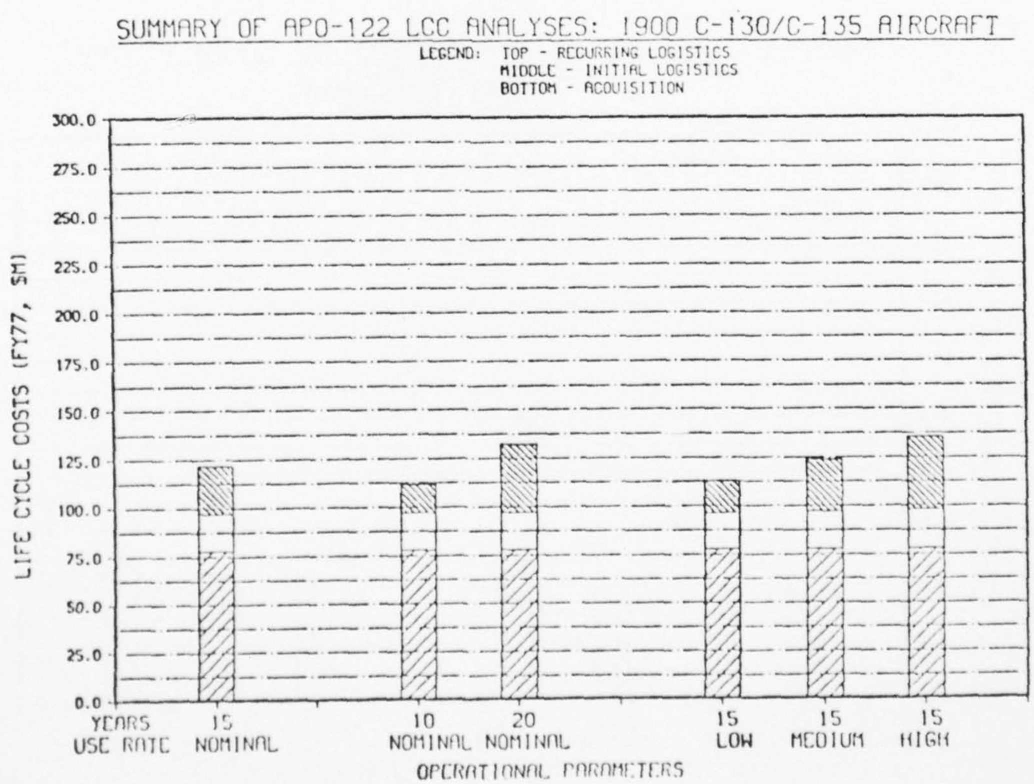
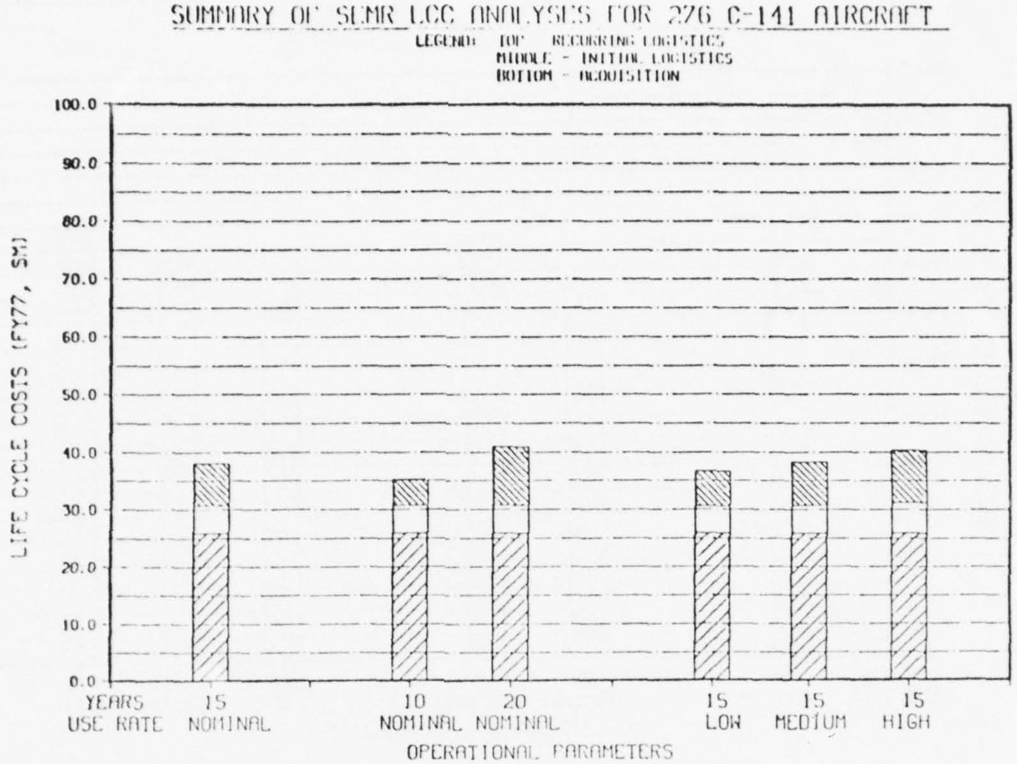


FIGURE 5. COMPARISON OF LCC ANALYSES FOR C-130/C-135 FORCE



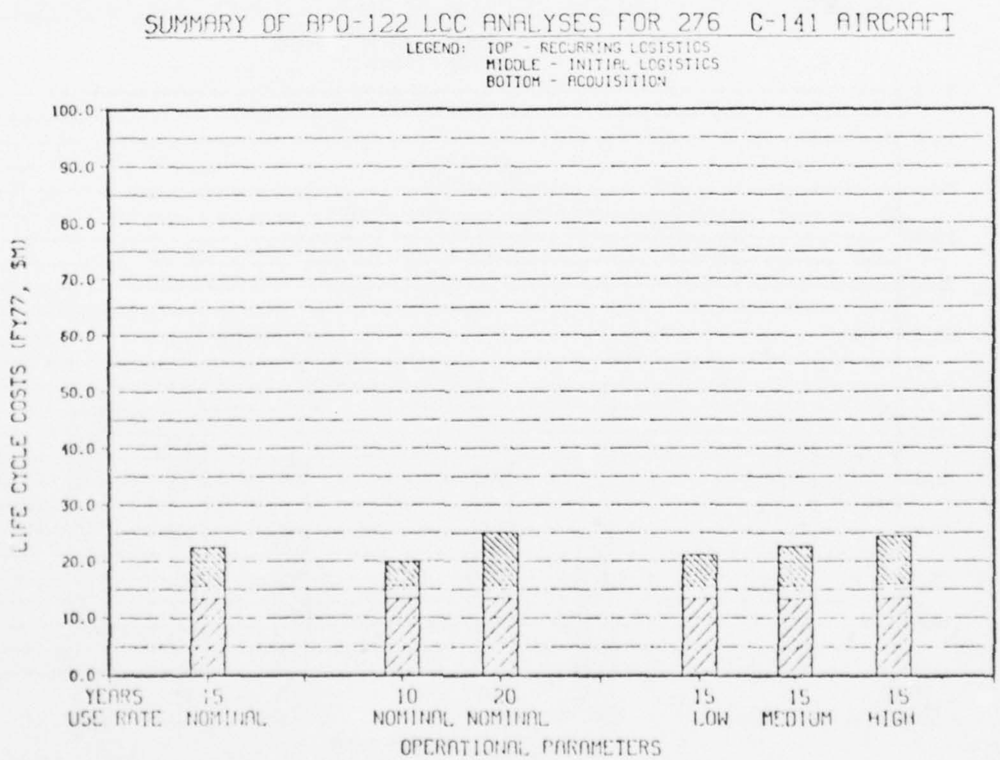
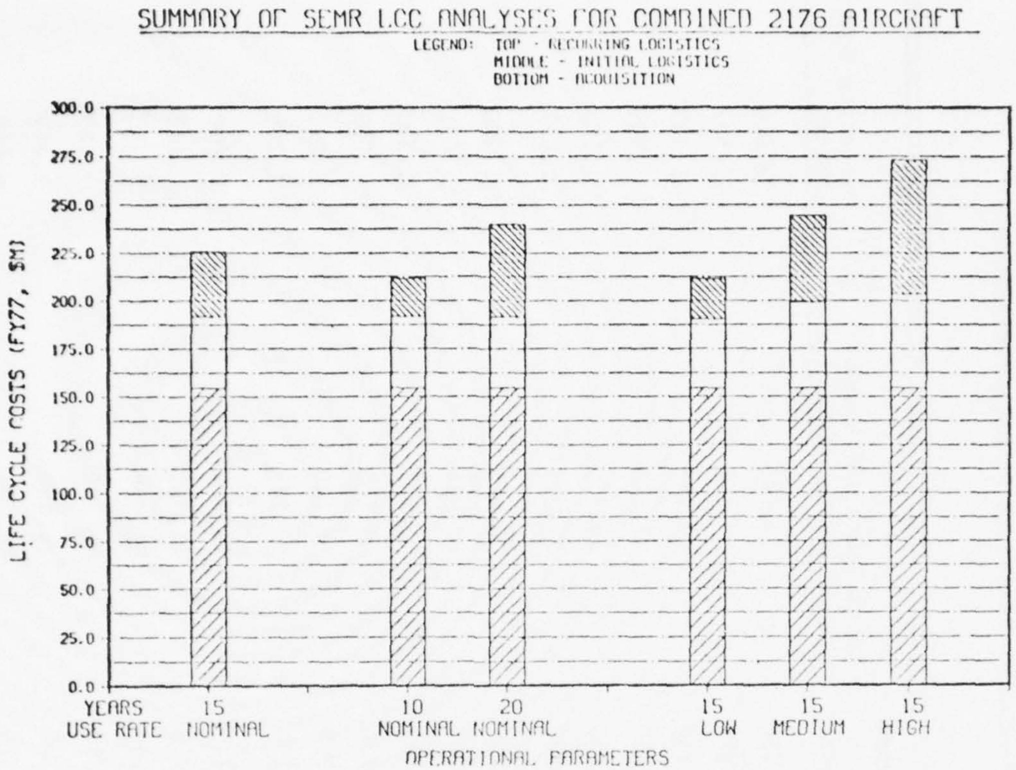


FIGURE 6. COMPARISON OF LCC ANALYSES FOR C-141 FORCE



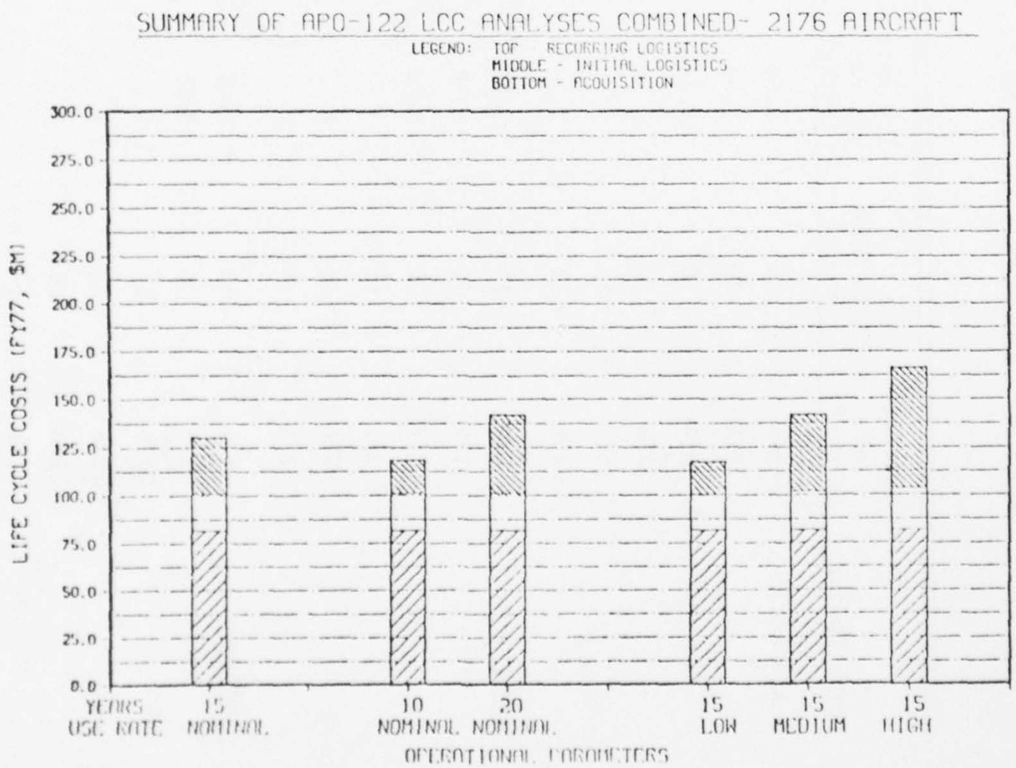


FIGURE 7. COMPARISON OF LCC ANALYSES FOR COMBINED FORCE

TABLE 38. TOTAL OPERATING HOURS FOR OPERATIONAL PARAMETER SENSITIVITY ANALYSIS

Force Option	Quantity of Aircraft	Life Time (years)	Use Rate per Day (hours)	Days per Year	Total Operating Hours* (in millions of hours)	Total Operating Hours Ratio
C-130/C-135	1900	15	1.81	250	12.896	1.000
	1900	10	1.81	250	8.598	.667
	1900	20	1.81	250	17.195	1.333
	1900	15	1	250	7.125	.552
	1900	15	2	250	14.250	1.105
	1900	15	3	250	21.375	1.657
C-141	276	15	3.88	250	4.016	1.000
	276	10	3.88	250	2.677	.667
	276	20	3.88	250	5.354	1.333
	276	15	3	250	3.105	.773
	276	15	4	250	4.140	1.031
	276	15	5	250	5.175	1.289
Combined	2176	15	2.07	250	16.891	1.000
	2176	10	2.07	250	11.261	.667
	2176	20	2.07	250	22.522	1.333
	2176	15	1	250	8.160	.483
	2176	15	3	250	24.480	1.449
	2176	15	5	250	40.800	2.415

*This column is the product of the preceding four columns.

then plotted against the operational hours scale to capture the sensitivity of the LCC estimates to the operational parameters. Figures 8, 9, and 10 present the plots for each force option. In each of these figures, four lines are drawn. Two lines show the sensitivity of the different LCC estimates to operational life periods and two lines show the sensitivity of the different LCC estimates to operational use rates. The plots in Figures 8, 9, and 10 represent linear connections between discrete data points. The operational life results are linear. The operational use rate results are not linear. This non-linearity is the result of the rounding-up feature in the spares algorithim in the GEMM program.

Figures 8, 9, and 10 graphically indicate steeper slopes for the SEMR-equivalent APQ-122 LCC estimates. The higher slopes can be interpreted as indicating that the SEMR-equivalent APQ-122 LCC estimates are more sensitive to the operational parameters than are the SEMR LCC estimates.

3.5.d. Implications of Discard Maintenance Policy

The SEMR LCC estimates were computed using a module-level discard at failure maintenance policy. The baseline estimates for SEMR-equivalent APQ-122 systems were computed using a module (SRU) repair at depot level policy. Tables 25, 26, and 27 presented the results of varying the primary operational parameters for APQ-122 systems with a module level discard policy. Figures 11, 12 and 13 show that the alternate policy does not significantly alter the SEMR-equivalent APQ-122 LCC estimates. An implication that may be inferred from this analysis is that the differences between the SEMR and SEMR-equivalent APQ-122 LCC estimates are not the result of the maintenance policy differences.

3.5.e. Implications of Reliability Degradation

The baseline LCC estimates for both the SEMR and the SEMR-equivalent APQ-122 systems were computed using predicted MTBF factors. Predictions were made, per References 1 and 13, in accordance with MIL HDBK 217 procedures.

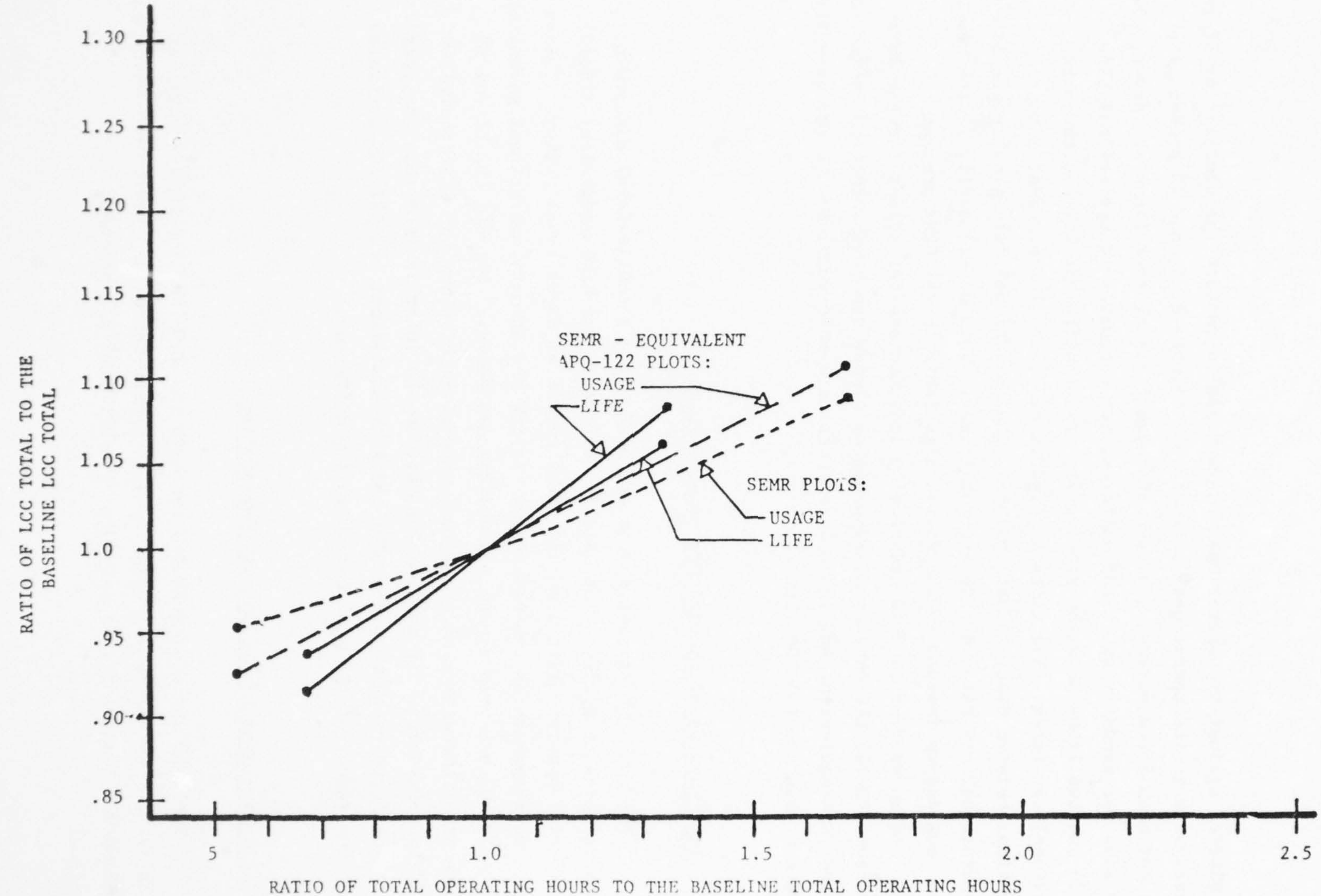


FIGURE 8. LCC SENSITIVITY TO OPERATIONAL PARAMETERS: C-130/C-135 FORCE

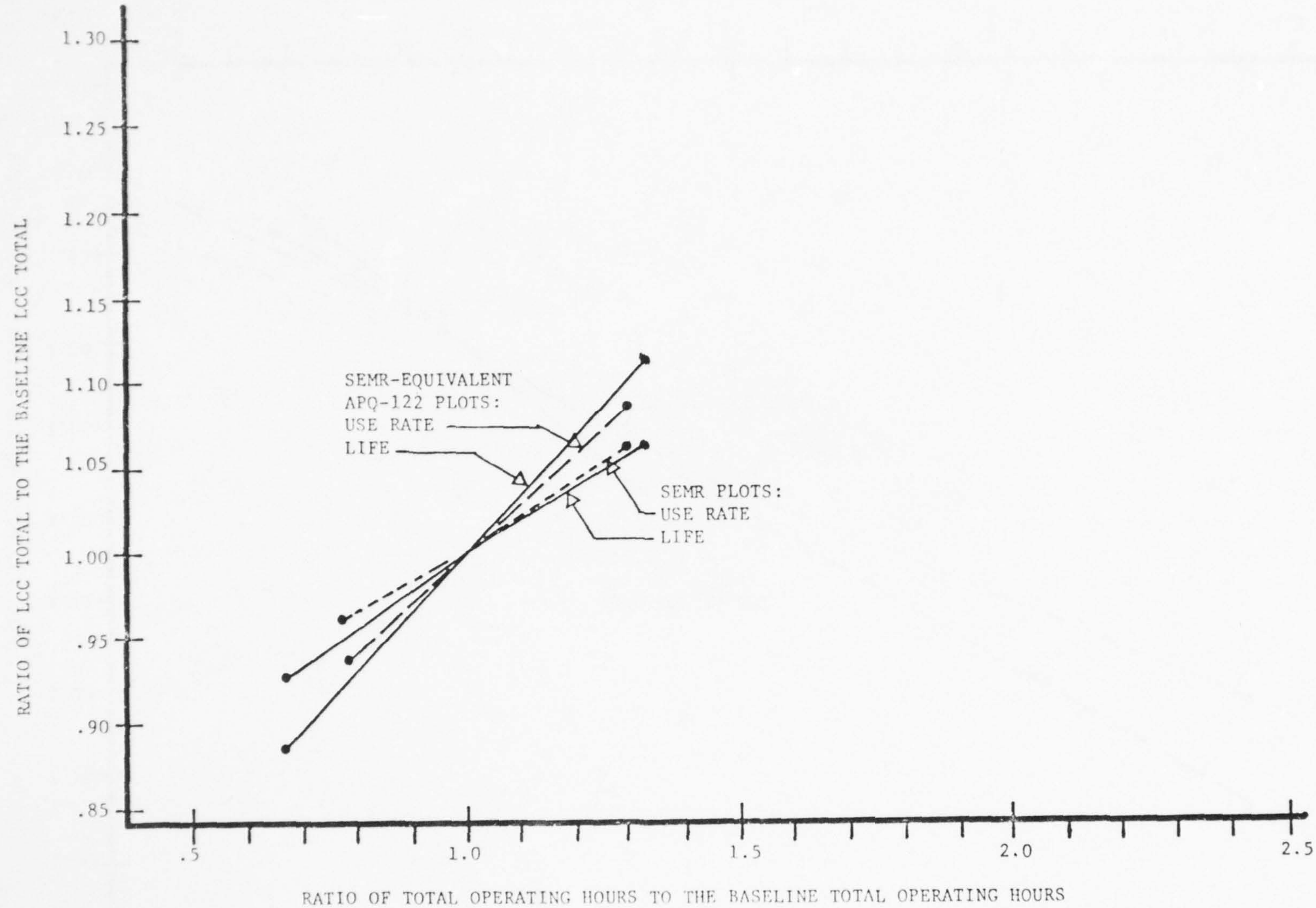


FIGURE 9. LCC SENSITIVITY TO OPERATIONAL PARAMETERS: C-141 FORCE

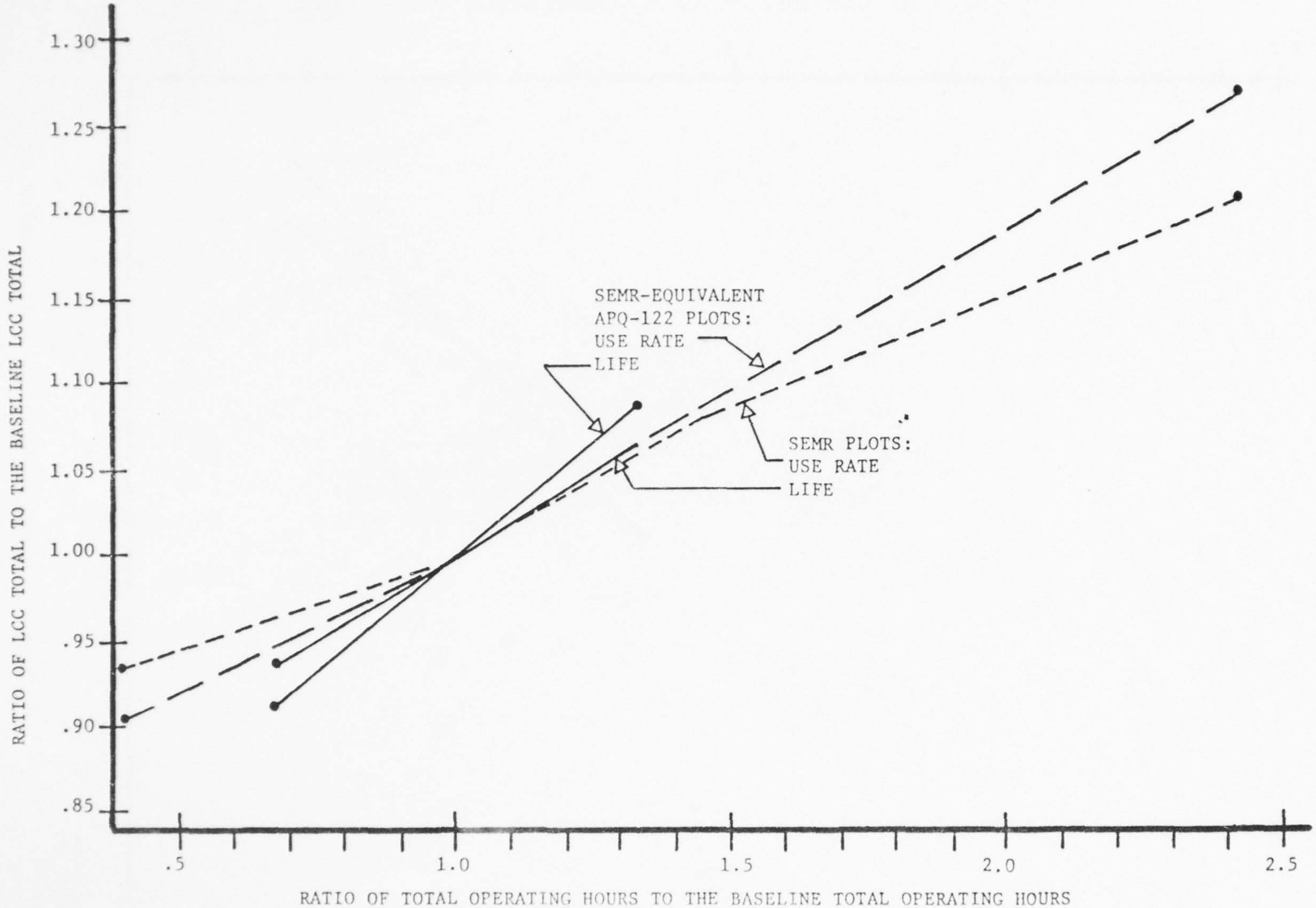


FIGURE 10. LCC SENSITIVITY TO OPERATIONAL PARAMETERS: COMBINED FORCE

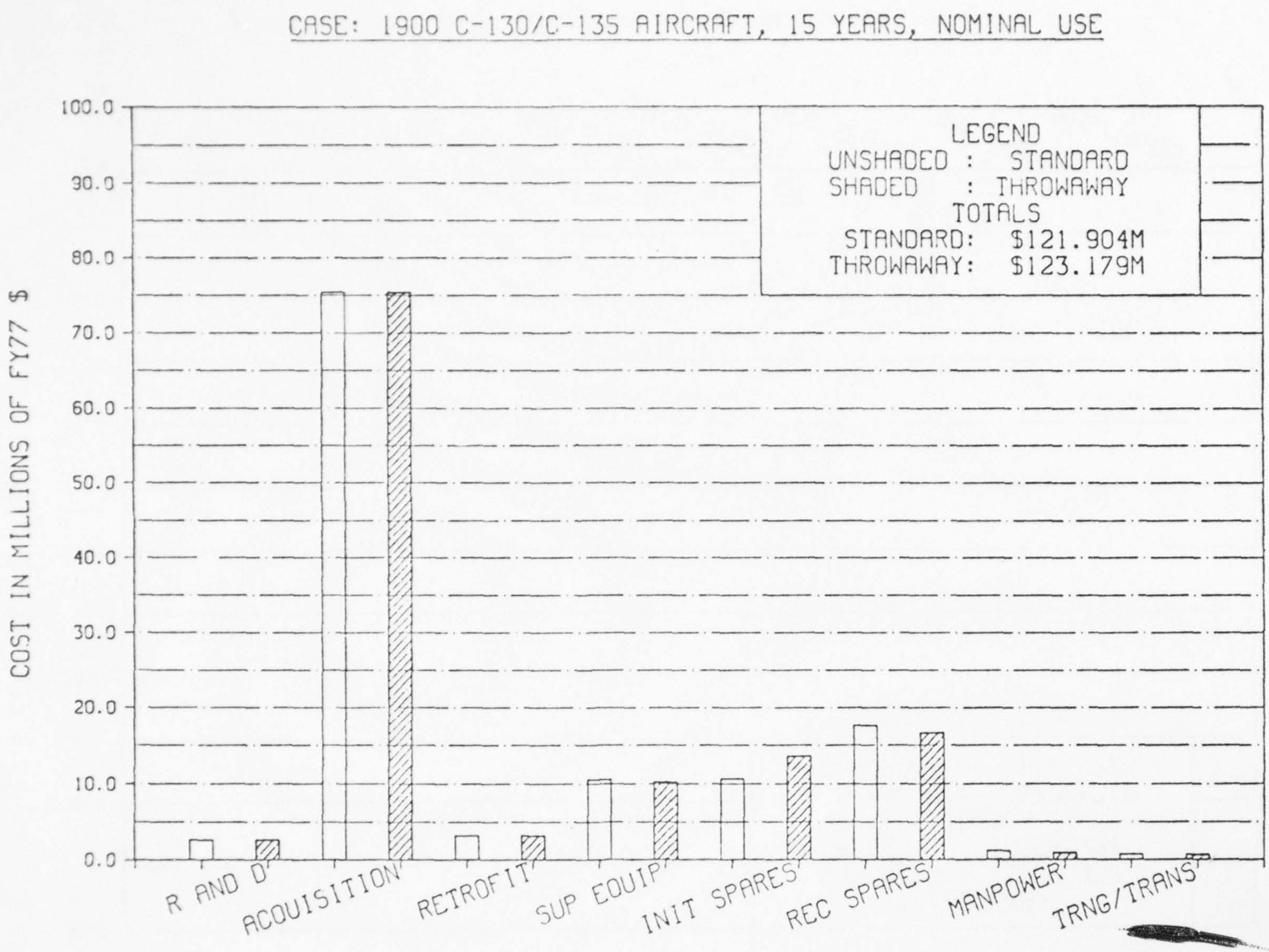


FIGURE 11. EFFECTS OF ALTERNATIVE MAINTENANCE POLICIES ON APQ-122

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STANDARD ELECTRONIC MODULE RADAR LIFE CYCLE COST COMPARISON.(U)

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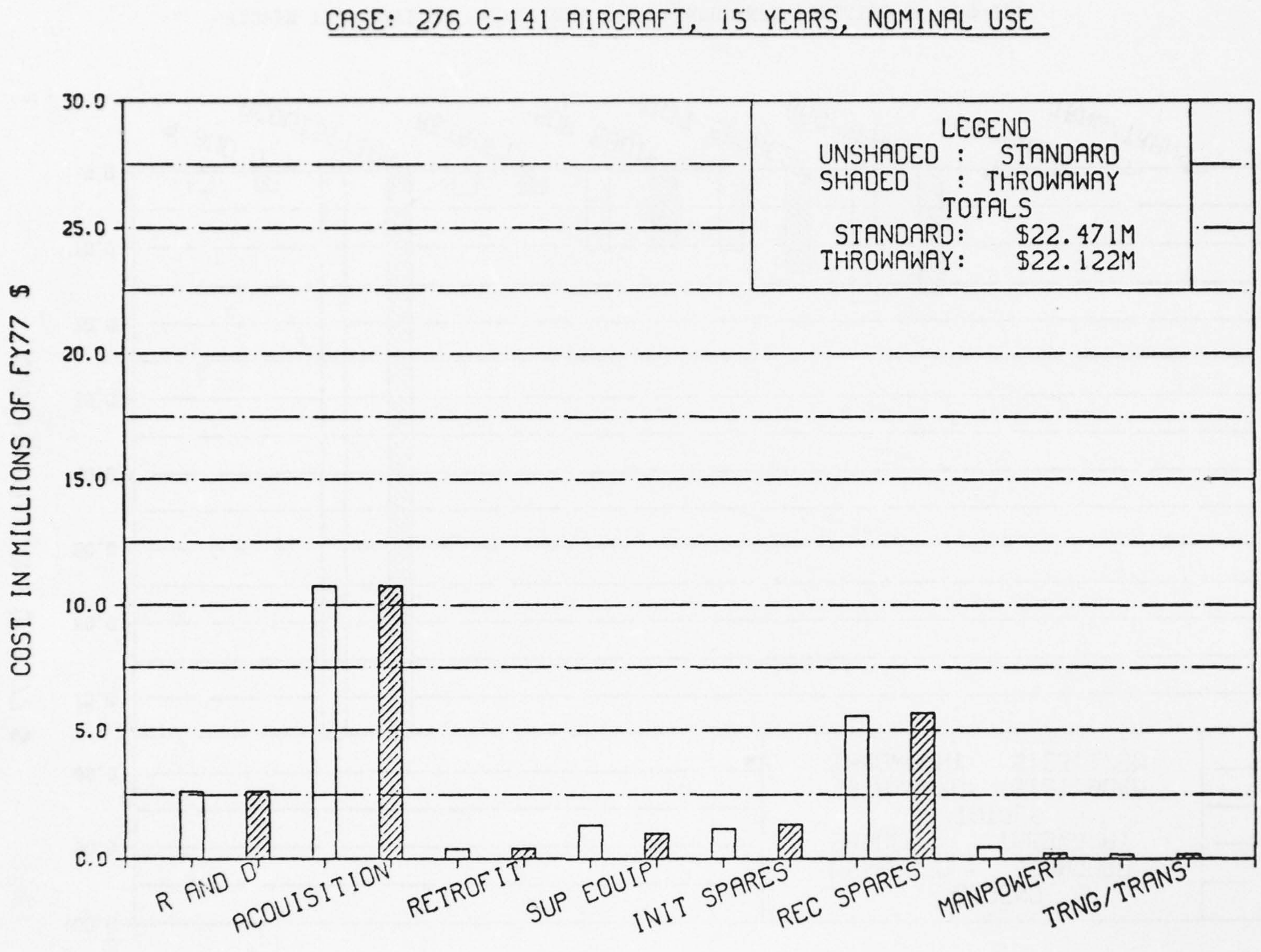

FIGURE 12. EFFECTS OF ALTERNATIVE MAINTENANCE POLICIES APQ-122

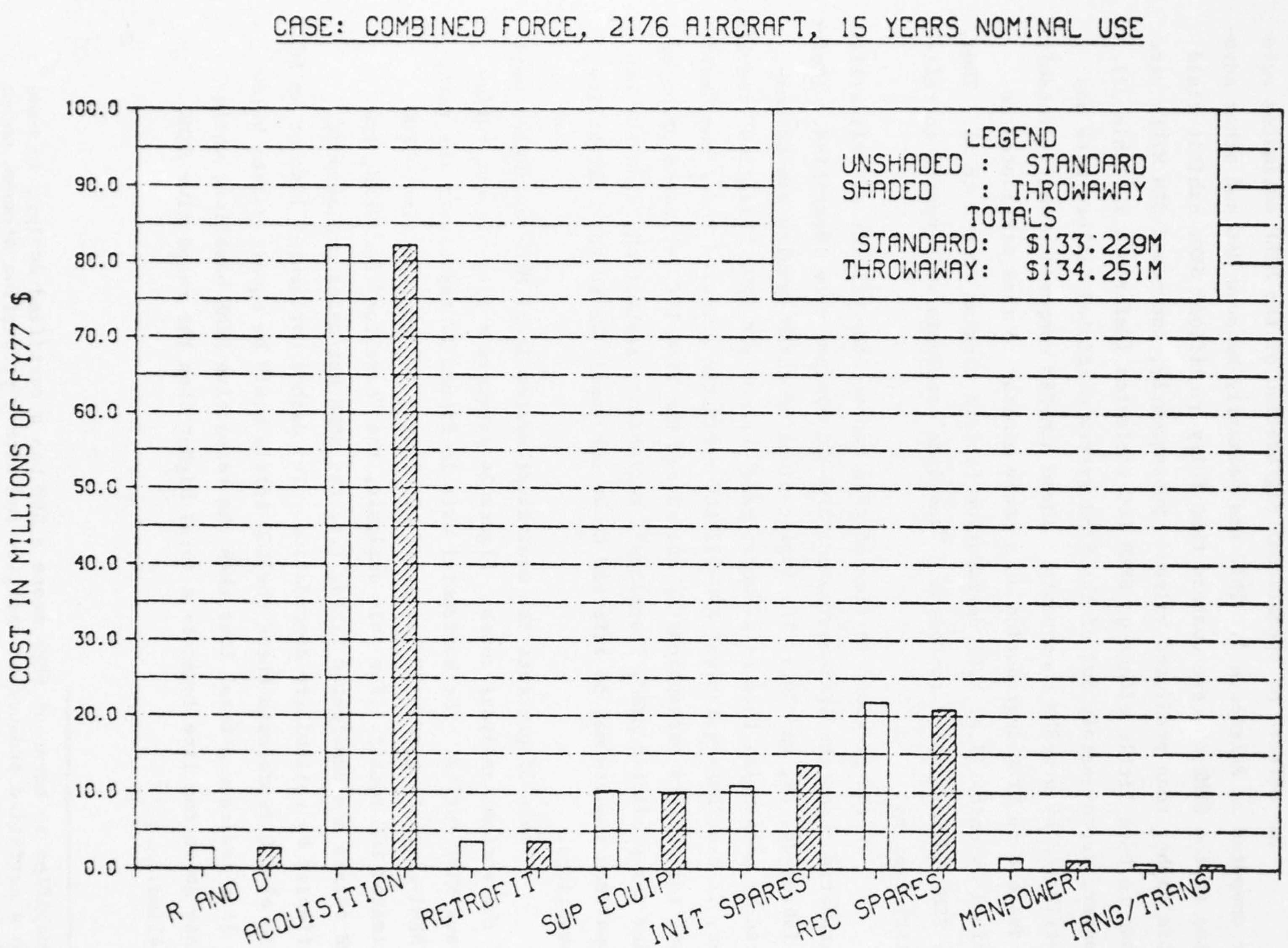

FIGURE 13. EFFECTS OF ALTERNATIVE MAINTENANCE POLICIES APQ-122

The effects of operational degradation of the MTBF estimates were not computed in Reference 1. This was primarily because NAC and other advocates of the SEMR concept contend that fully qualified* SEMs exhibit field MTBFs higher than predicted values. Subsequently, increased SEM MTBFs were shown to have little effect on SEMR LCC estimates (Reference 1, Table 22). However, approximately 50% of the SEMR system predicted failure rate was contributed by non-SEM components. Those non-SEM components would probably be subject to MTBF degradation on a scale similar to that attributed to typical avionics (i.e. MTBF degradation factors ranging from 2 to 5). Thus, the SEMR LCC estimates represent a "baseline" analysis with regard to reliability factors.

In the previous section of this report, the effects of reliability degradation upon the SEMR-equivalent APQ-122 systems were identified. (Refer to Tables 28, 29, and 30.) The implications of those results can be analyzed by presenting them as a "worst-case" versus the SEMR "baseline" results. Thus, if the SEMR-equivalent APQ-122 LCC estimates prepared under the "worst-case" reliability assumptions do not exceed the SEMR LCC estimates prepared under the predicted MTBF, "baseline", reliability assumption, then the LCC comparison results may be inferred to be not sensitive to the reliability assumptions.

Table 39 presents the equivalent system level MTBF estimates used for the various analysis cases. Figure 14 presents a plot of cost ratios versus MTBF ratios. The horizontal axis in Figure 14 represents the ratio of SEMR-equivalent APQ-122 estimated LCC totals to the repective, SEMR estimated LCC totals. For this analysis, the "baseline" for SEMR, the SEMR totals are considered fixed, i.e. the SEMR estimates are assumed uneffected by reliability degradation. The dashed horizontal line at an LCC ratio of 1.0 represents where the LCC totals would be equal; points below the line indicate a total less than the respective SEMR baseline, while points above the line indicate a total higher than the respective SEMR baseline.

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* Qualified in terms of SEMP means a SEM has a certified design, is made in a certified production facility and with a production process under thorough qyality control.

TABLE 39. SYSTEM LEVEL MTBF ESTIMATES

	FORCE OPTIONS		
	C-130/C-135	C-141	COMBINED
SEMR			
Predicted MTBF	191.5*	208	193.5
SEMR EQUIVALENT			
APQ-122 SYSTEM			
Predicted MTBF	410.5	585.5	410.5
.5 x Predicted	205.25	292.75	205.25
.2 x Predicted	82.10	117.10	82.10

* All units are in hours.

The curves in Figure 14 represent the increase in the LCC ratio corresponding to a decrease in the reliability. The shape of the curves are typical for LCC analyses where costs are plotted against MTBF values. In reality, the SEMR LCC estimates would be expected to rise dramatically over the same scale of MTBF ratios but are shown fixed for the "best case - worst case" comparison.

Interpretation of Figure 14 reveals that the LCC estimate for the "worst case" considered for the SEMR-equivalent APQ-122 systems in the C-141 force exceeds the SEMR "baseline" by approximately 9%. The "worst-case" estimates considered for the other two force options remain below the SEMR "baseline" estimates. The sensitivity of the C-141 case can be explained by noting that the baseline use rate for the C-141 force is significantly higher than for the C-130/C-135 force (3.88 hours per day versus 1.81 hours per day). The higher use rate results in a proportionately higher number of failures when the MTBF is reduced.

The preceding analysis can be used to indicate the effect of the estimating error in the MTBF values used in the development of SEMR-equivalent that the error could be as large as a factor of 2 and the basic comparisons would not be affected.

3.6 Implications of Price-Quantity Sensitivity Analyses

Both the SEMR and SEMR-equivalent APQ-122 baseline LCC analyses have used a 90% progress curve for estimating cumulative average unit costs at specific production quanties. It was noted earlier that the original vendor quotes for the APQ-122V(5) system were equivalent to a 92% progress curve. If the 92% is assumed more appropriate for a design with custom sub-assemblies and circuit boards, then the effects of a 92% curve are important to analyze. For this purpose, the sensitivity of the SEMR-equivalent APQ-122 LCC estimates to the different progress curve factors were computed and presented in Table 32. The adjusted results are presented in Table 40. Even with the more conservative progress curve for the SEMR-equivalent APQ-122 system, the LCC totals remain 25 to 30% below the respective SEMR totals and the basic comparison findings remain uneffected.

TABLE 40. COMPARISON OF LCC TOTALS ADJUSTED FOR A DIFFERENT PROGRESS CURVE

(Millions of FY 77 Dollars)

	SEMR LCC Total	SEMR-Equivalent APQ-122 Adjusted LCC Totals	Differences	Difference as a percent of SEMR Total
Force Option:				
C-130/C-135	204.316	153.661	50.655	24.8%
C-141	38.076	26.217	11.859	31.1%
COMBINED	225.686	168.658	57.028	25.3%

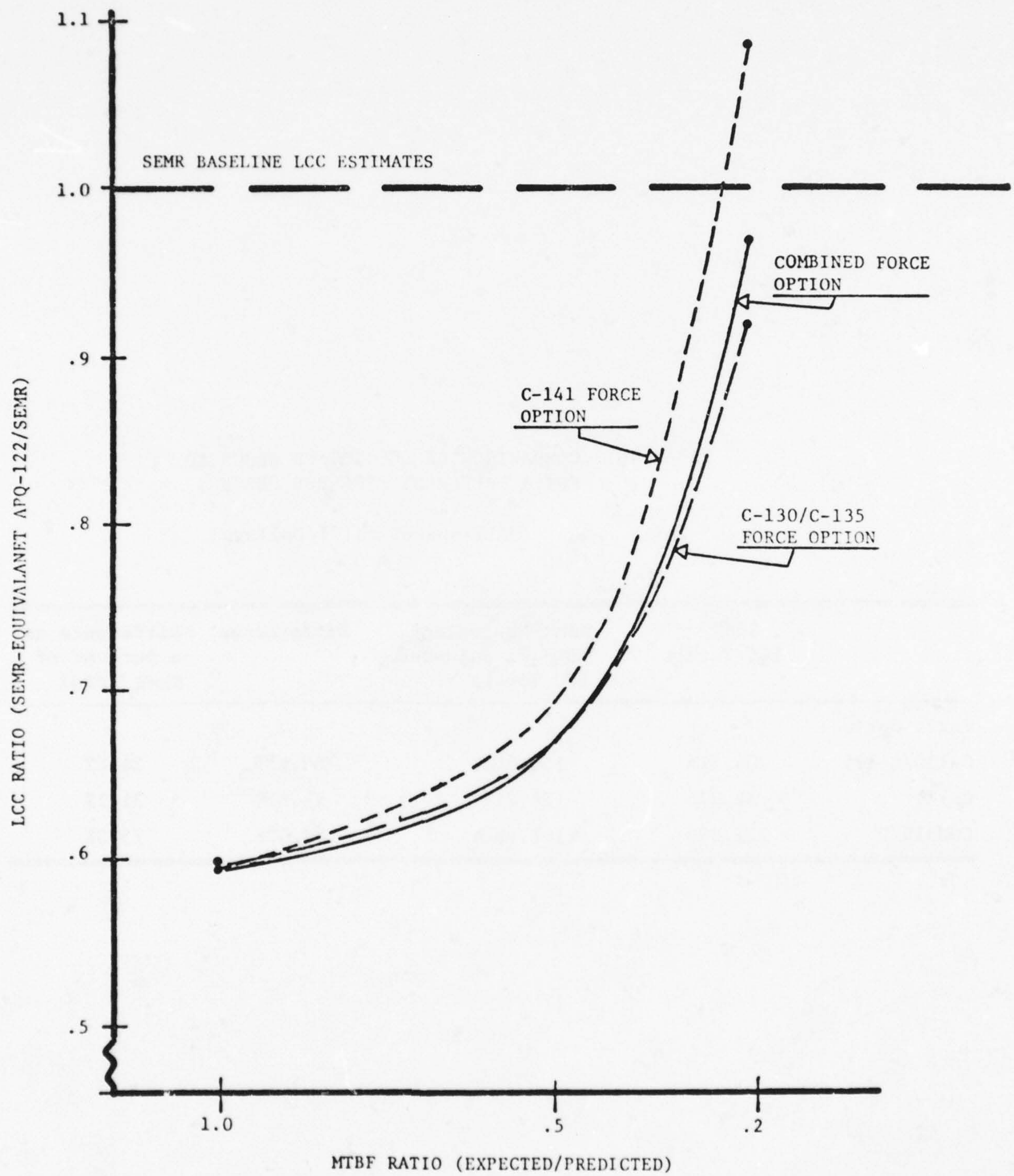

FIGURE 14. SEMR EQUIVALENT APQ-122 LCC ESTIMATES SENSITIVITY TO RELIABILITY DEGRADATION

3.7 Implications of a Higher Economic Escalation Factor

References and rationale for using a FY-72 base to FY-77 base conversion factor of 1.428 were described earlier. It was also mentioned that a higher rate might be considered more appropriate under the assumption that manufacturing an FY-72 design in FY-77 would not benefit from manufacturing technology enhancements which could be buried in the 1.428 factor. Accordingly, the effects of using a factor based on the wholesale price index were computed and presented in Table 34. A summary of the adjusted results are presented in Table 41. The basic comparison findings remain unchanged by the higher factor with the SEMR-equivalent APQ-122 LCC estimates still 32% lower than the SEMR estimates.

TABLE 41 COMPARISON OF LCC TOTALS WITH A HIGHER ESCALATION FACTOR

(Millions of FY-77 dollars)

	SEMR LCC Total	SEMR-Equivalent APQ-122 Adjusted	Difference	Difference as a Percent of SEMR Total
Force Option:				
C-130/C-135	204.316	139.548	64.768	31.7%
C-141	38.076	25.681	12.395	32.6%
Combined	225.686	152.493	73.193	32.4%

3.8 Review of Hypothetical SEMR Design Changes

The purpose of this activity was to review the hypothetical design changes to the SEMR which were described by NAC in NAC TR-2225 (Reference 6), and identify the significant LCC implications. Of particular interest is the potential implications upon the LCC comparison analysis presented in the preceding sections of this report. The hypothetical changes discussed in Reference 6 include:

- o the modular power supplies would be replaced by supplies of more conventional design in a separate power supply assembly.
- o the BITE would be replaced by a portable test set with a resulting deletion of the remote BITE control box.
- o the receiver-transmitter would be reorganized and incorporate the electronics of the display electronics unit.

From a LRU configuration basis, these changes would introduce one new LRU (power supply) and delete two (display electronics unit and remote BITE control box). The technical details of the hypothetical changes have not been sufficiently defined to support a complete redevelopment of the SEMR LCC estimates. However, the potential effects are estimated and the implications are discussed in the following paragraphs.

3.8.a. Potential LCC Effects of Design Changes

The most significant SEMR design change of those suggested in reference 6 appears to be the removal of the detailed BITE system. An analysis of the SEMR system without SEM-level BITE capability on board the aircraft was performed in the previous SEMR LCC study. That analysis indicated a potential baseline LCC decrease of 7.85% for the C-130/C-135 force (Reference 1, Table 23). Similar computations with approximately proportional results can be assumed.

The next most significant change appears to be the removal of the SEM oriented power supply assemblies and replacing them with a conventionally designed power supply unit. The effects of this change have been developed by estimating the costs of the power supply unit using a procedure consistent with the procedures used in the SEMR study. Table 42 presents the data used to develop a power supply unit cost. The columns and rows in Table 42 reflect the following step by step procedure:

TABLE 42. POWER SUPPLY ASSEMBLY UNIT COST ESTIMATION

Subassemblies	Small Quantity Unit Cost	Computed Unit Costs for Quantity Lots		
		Quantity = 276	Quantity = 1900	Quantity = 2176
Required				
+5 Volt, 30 amp Module	725	308	230	225
+15 Volt, 10 amp Module	725	308	230	225
-15 Volt, 10 amp Module	725	308	230	225
+15 Volt, 4 amp Module	595	253	189	185
-15 Volt, 4 amp Module	595	253	189	185
Two DC Converters	178	76	57	55
Initial Totals		1506	1125	1100
Totals Adjusted for LRU Integration		1732	1294	1265
Totals Adjusted for $FY 77 Base		1525	1140	1114

- o identify subassemblies required (column 1)
- o establish commercially available price for small quantities (column 2)
- o adjust column 2 data for quantities (columns 3, 4, and 5)
- o sum to component totals
- o adjust totals for LRU integration cost (+15%)
- o adjust totals for FY 77 base dollars (.8806 from Reference 20)

The commercial prices are reflective of modules close in size and weight to those described in the NAC report.

The system and modulation power supply assemblies were not separate units in the SEMR analysis. For this analysis, their estimated costs were determined by summing the costs of the SEM's in each assembly, adding the card cage cost estimate and multiplying by the 15% integration factor. The results are shown combined in the first cost column of Table 43 The remainder of Table 43 develops the estimated effects of the conventional power supplies on the SEMR acquisition costs for the three force options considered. Because the system acquisition costs dominate all the other cost categories and directly influence the other major LCC components, support equipment and spares, an optimistic* approximation of the effect on the LCC total can be computed by extrapolating the acquisition cost reduction percentages to the LCC totals. Using this assumption, the last column in Table 43 indicates an approximated impact on the SEMR LCC baseline totals.

The restructuring of the receiver-transmitter assemblies as described in reference 6 is not considered to have a significant potential effect on the LCC estimates. No items are removed from the system and the relative complexity of the receiver-transmitter unit is the same.

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*The approximation is considered to be optimistic for the SEMR because it is assumed that the logistics support costs of the subassemblies in the convential power supply would not be more than the support costs of the relatively reliable SEM's being replaced.

TABLE 43. COMPARISON OF POWER SUPPLY COSTS

Force Option	Quantity Required	Estimated SEM Power Supplies Combined Unit Cost	Estimated Unit Cost for Conventional Assembly	Unit Cost Difference	Force Level Differences in millions	Force Level Differences in percentage of System Acquisition Total	LCC Approximated Impact in millions
C-130/C-135	1900	3490	1140	02350	-4.465	-3.2%	-6.538
C-141	276	4680	1525	-3155	- .871	-3.6%	-1.371
Combined	2176	3419	1114	-3305	-5.016	-3.3%	-7.448

3.8.b. Implications of Hypothetical Changes

The approximated combined effects of the BITE and power supply changes upon SEMR LCC estimates are presented in Table 44. In addition, the adjusted LCC totals are compared to the baseline LCC totals for the SEMR-equivalent APQ-122 systems. The results presented in Table 44.

TABLE 44. LCC IMPLICATIONS OF HYPOTHETICAL DESIGN CHANGES

(Millions of FY 77 Dollars)

Force Option	Baseline SEMR LCC Total	Decreases in LCC for: Bits Removal	Decreases in LCC for: Power Supplies	Decreases in LCC for: Adjusted Baseline	SEMR-Equivalent APQ-122 LCC Baseline	Difference	Difference as a Percentage of Adjusted SEMR Baseline
C-130/C-135	204.316	16.039	6.538	181.739	121.904	-59.835	32.9%
C-141	38.076	2.989	1.371	33.716	22.471	-11.245	33.4%
Combined	225.686	17.716	7.448	200.522	133.229	-67.293	33.6%

SECTION IV

STATEMENT OF FINDINGS AND CONCLUSIONS

The preceding section of this report has described the development of LCC estimates for a solid-state radar functionally similar to the SEMR and compared those LCC estimates to LCC estimates for the SEMR as developed during a previous study. The estimates were computed and compared in accordance with the procedures described in the Study Approach Section of this report and the statement of work for the study. The findings and conclusions of this study are presented in the following subsections.

4.1 Statement of Findings

The procedures and analyses of this study support the following findings:

(1) When using data collection and analysis procedures and assumptions consistent with those used in developing SEMR LCC estimates, the baseline LCC estimates for a SEMR-equivalent APQ-122 system were computed to be approximately 40 percent less than the SEMR LCC estimates.

(2) The baseline LCC estimates for both systems were found to be dominated by the acquisition costs.

(3) The LCC estimates for the SEMR-equivalent APQ-122 systems were found to be slightly more sensitive to the operational parameters of operating life and use rate but not to a degree which altered the first finding stated above.

(4) The LCC estimates for the SEMR-equivalent APQ-122 systems computed using an SRU repair at depot maintenance policy were found to not be significantly changed by an SRU discard-at-failure policy.

(5) The LCC estimates for the SEMR-equivalent APQ-122 systems computed using predicted MTBF values were found to be sensitive to MTBF degradation but not to an extent which would affect the first finding above.

(6) When using a significantly higher value for each of two parameters critical to the cost estimating procedures (progress curve and escalation factors), higher LCC estimates for the SEMR-equivalent APQ-122 systems were computed but the adjusted estimates were still found to be at least 25 percent less than the baseline LCC estimates for the SEMR.

(7) The LCC impact of conceptually defined SEMR design changes was found to be a potential decrease in the SEMR LCC estimates but the approximated decrease was not large enough to alter the previous findings of the comparison study.

4.2 Conclusions

The procedure, assumptions, and findings of this study support the following conclusions:

(1) The LCC estimates developed in this study for SEMR-equivalent APQ-122 systems are sensitive to the assumptions made regarding progress curve factors, economic escalation factors, and system reliability estimates.

(2) The LCC estimates developed in this study for SEMR-equivalent APQ-122 systems are lower than comparable LCC estimates for SEMR systems over the examined ranges of critical variables.

APPENDIX A

GENERAL DESCRIPTION OF THE GENERALIZED ELECTRONIC MAINTENANCE MODEL

A.1 INTRODUCTION

The Generalized Electronics Maintenance Model, GEMM, is a management tool designed to aid decision makers in the development of prime equipment and its supporting logistics system. Implementation of this model provides the manager with the opportunity to study the interaction of the logistic support elements and the effect each element has on the system life cycle costs. The program itself is written in Fortran IV computer language and includes several cost equations and algorithms addressing such categories as R&D costs, Acquisition Costs and Logistic support costs. A feature of the GEMM is its sensitivity analysis option which facilitates evaluation of alternative designs and support concepts.

A.2 MAINTENANCE PHILOSOPHY DESCRIPTION

GEMM was originally developed for, and is most widely used, U. S. Army Systems. In the Army maintenance philosophy, there exists 4 categories or levels of maintenance: Organizational Support (O); Direct Support (DS); General Support (GS); and Depot Support (D). There typically exists a general maintenance structure on the type of work done at each level, persons performing the work, equipment that is maintained and the basis of the repair action. GEMM includes, but is not restricted to, this existing organizational structure. To evaluate both the existing maintenance structure and alternative structures it is necessary to classify maintenance actions: Check-out-Equipment (COE); Fault Isolate (FI); Throw Away (TA). The units under maintenance consideration are Components (C), which contain Modules (M), which contain Parts (P).

To apply the GEMM model to Air Force systems, the following transforms of the terms identified above are appropriate.

Levels of Maintenance:

Organizational (O) ⟶ Flight Line Organization

Direct Support (DS) ⟶ Intermediate Base Shop

General Support (GS) ⟶ Intra theatre depot

Depot Support (D) ⟶ Depot

Units under maintenance:

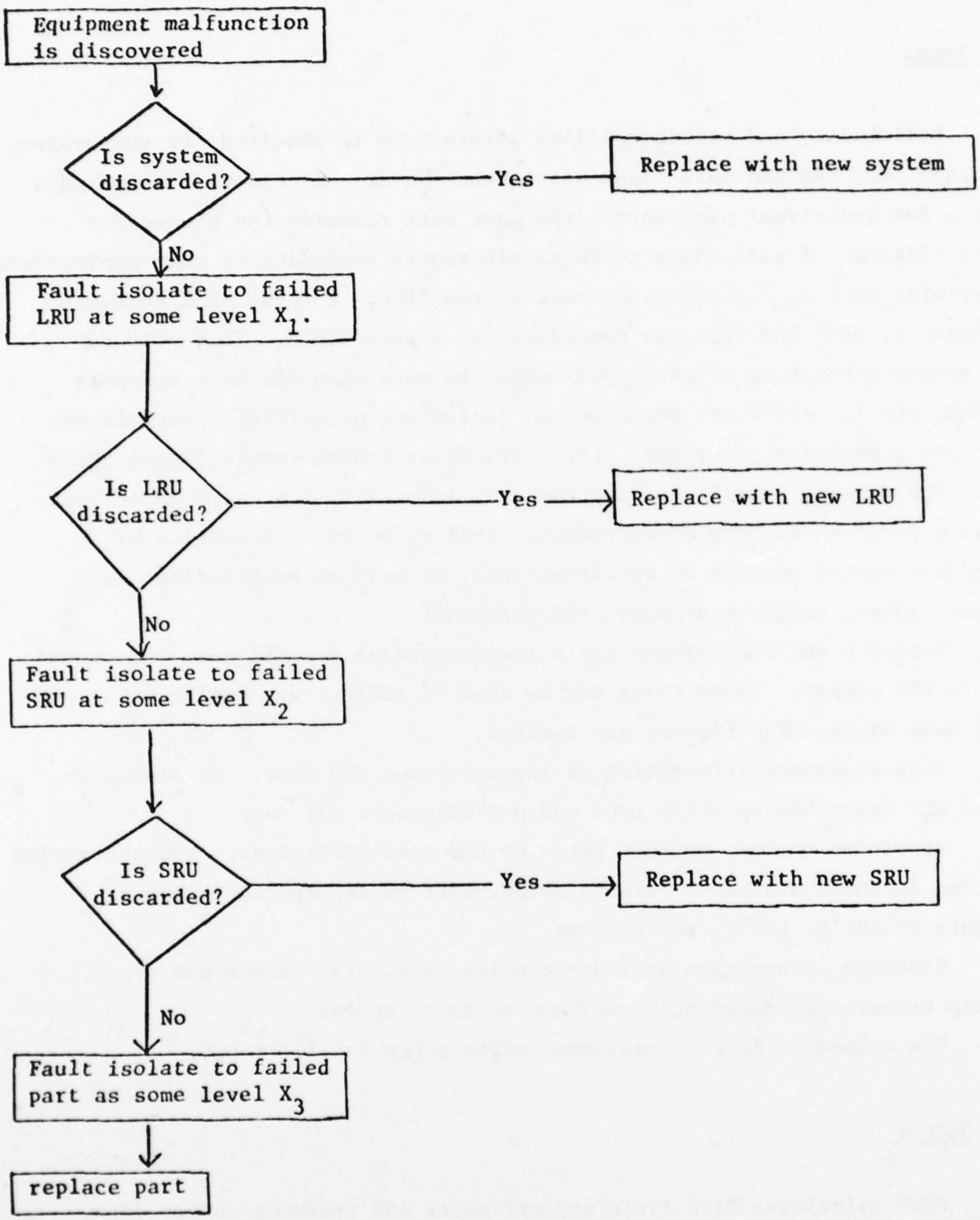
Components ⟶ Line Replaceable Units (LRU)

Modules ⟶ Shop Replaceable Units (SRU)

Parts ⟶ Piece parts

Part of the input required for GEMM is the specification of a maintenance philosophy. Checking out on-equipment (COE) is the only maintenance action that is restricted. COE must be accomplished at the organizational support level. COE is the action required to determine that the system has failed. It is followed by definition of a maintenance philosophy coded in the following form: Maintenance action-unit upon which action is taken--level of maintenance support. For example, FICDS represents fault isolation of a component (LRU) at the direct support (intermediate) level. Logically, equipment must be identified as inoperable before a component within the equipment is identified as inoperable; a component must be inoperable before a module within it is deemed inoperable; and a module must be inoperable before a part within it is identified as inoperable. With the exception of COE, as noted above, any maintenance action can be achieved at any level of support.

A maintenance concept is a specified sequence of decisions which can generally be charted as follows:


Equipment malfunction is discovered
Is system discarded?
Yes
Replace with new system
No
Fault isolate to failed LRU at some level X_1.
Is LRU discarded?
Yes
Replace with new LRU
No
Fault isolate to failed SRU at some level X_2
Is SRU discarded?
Yes
Replace with new SRU
No
Fault isolate to failed part as some level X_3
replace part

A.3 PROGRAM DESCRIPTION

A.3.a. Input

Reliability and maintainability information is required for the system, and for each LRU, SRU and part class within the system. In order to avoid data collection for individual pieceparts, the user must classify the pieceparts into part classes. A part class collects pieceparts according to some appropriate characteristic such as failure rate, cost or the like. For the SEMR analysis is reference 4, each SEM type was considered as a part class. This allowed for the proper accounting of SEM types common to more than one SEMR assembly (BITE, T&C, etc.). SRU's are described as consisting of multiple part classes (in discrete quantities per type). LRU's are described as consisting of SRU's.

The mission profile for any end item (aircraft) must also be entered. The mission profile consists of information such as hours of operation of end item/day; number of days of operation/year, as well as restrictions on maintenance shops, repair equipment, and personnel.

Research and development costs are entered as a total cost and passed through to the output. These costs may be used to reflect the higher R&D costs incurred when higher MTBF figures are desired.

Test equipment information is input by type and cost. Maintenance personnel are described by skill type and pay allowance per year.

Attrition factors reflect peace or war time conditions. Transportation information includes distances between shops, cost of transportation/pound and weights of SRU's, LRU's, and systems.

Stockage information includes confidence levels, turnaround times, order-ship times, replenishment times, and costs of spares.

The economic life of equipment under study is also input.

A.3.b. Output

GEMM calculates life cycle support costs and produces output data for the following categories:

1. Test Equipment Cost
2. Spares and Repair Parts Costs
3. Personnel Costs
4. Transportation Costs
5. Training Costs
6. Inventory Management Costs
7. Publication Costs
8. R&D Costs
9. Production Costs

A.3.c. Key Equations

The key relationships utilized internally within the calculation portion of GEMM involve:

1. Annual Maintenance Manhour (AMMH)
2. Test Equipment Requirements
3. Manpower Requirements
4. Transportation and Stockage Requirements

The Annual Maintenance Manhour subroutine is exercised for each SRU, LRU, and system to determine the Annual Maintenance Manhour (AMMH) requirements for maintenance. AMMH is defined as (number of failures/year) x (mean time to repair/failure).

Test equipment is identified by "type". The quantity of "type i" test equipment required for the unit under test is the annual maintenance manhours for the unit under test divided by the number of shop hours available per year, multiplied by the number of units under testing per shop. The total test equipment requirement for the entire force structure considers the requirements per shop and the number of shops per force structure.

Maintenance manpower calculations are determined by the AMMH of the unit under test divided by personnel hours available, where AMMH has been previously calculated and personnel hours available data is input.

For stockage calculations, stock is subdivided into non-repairable stock, such as parts and throw away items, and repairable stock. Nonrepairable stockage contains the initial issue quantity (stock that accompanies the initial deployment of an end item), the order ship quantity (that which is necessary to fill stockage pipeline) and the replacement quantity (the nonrepairable stock located at the depot that is utilized as back-up for field stockage). Repairable stock contains only the stockage required in the stockage pipeline to replace a failed item as it is being repaired.

Initial Issue Stock at a particular support shop is a function of mean demand for the item and a given protection level. For the entire force structure, total stock required is the initial issue/shop multiplied by the number of shops in a force structure. The total initial provisioning per force structure is the sum of Initial Issue Stock, Order Ship Stock and replacement stock for each price structure. Pipeline stockage is the only requirement for repairable stock. Pipeline stockage per shop is based on mean demand for the stock and an input protection level. Pipeline stock for the force structure is the product of pipeline stockage per shop and the number of shops/force structure. Reorder stock is based on consumption rate. For nonrepairable items reorder stock is equal to the number of failures expected in the force structure and the life cycle plus the number of failures caused by attrition. For repairables, reorder stock is the number of failures caused by attrition.

For training costs, the algorithm is:

Training costs = number of personnel skill types x Cost of Training per skill type x Life Cycle in years ÷ turnover rate.

For publication costs, the algorithm is:

Publications Cost = Cost per page x number of pages required for given maintenance action.

Finally, Research and Development costs are input to the model. Production costs are estimated on the basis of prime equipment costs and also passed through to the output.

A.3.d. Sensitivity Analysis

The sensitivity analysis capability of GEMM has two major purposes. These are (1) To determine the effects that changes in key variables or changes in combinations of variables exert on support life cycle costs, and (2) To determine how sensitive a variable is, that is, how much system values (e.g. MTBF or MTTR) would change when a given variable is varied over a range of values.

The following parameters may be varied over a range of values either separately or in combination with others: MTBF, MTTR, Cost of Equipment, Test Equipment Information, Manpower Information, Weight of Equipment, Force Structure, Transportation Information, Requisition Times, Operating Hours/Shop, Stockage Confidence Limits, Attrition Rate, Stockage Objectives and Order-Shipping Time, Economic Life, Training Factors, Inventory Management Factors, Maintenance Policies, R&D Costs, Round up Option, Maintenance Publications, and Overhaul Considerations. Using sensitivity analysis it is possible to obtain different combinations of life cycle costs and operational availability for different values of key system parameters. From these combinations of output, it is possible to eliminate combinations of parameters which do not meet operational constraints.

APPENDIX B

LIST OF ACRONYMS

AFAL - Air Force Avionics Laboratory

AFIT - Air Force Institute of Technology

AFLC - Air Force Logistics Command

AFSC - Air Force Systems Command

ALC - air logistics center

ASD - Aeronautical Systems Division

BITE - built in test equipment

DAF - discard at failure

GEMM - Generalized Electronics Maintenance Model

GFE - government furnished equipment

LRU - line replaceable unit

MTBF - mean time between failure

MTTR - mean time to repair

NAC - Naval Avionics Center

NAFI - Naval Avionics Facility - Indianapolis

Q - quantity

PC - progress curve

R - repairable

SEM - standard electronic module

SEMP - Standard Electronic Module Program

SEMR - Standard Electronic Module Radar

SRU - shop replaceable unit

TI - Texas Instruments, Inc.

TR - technical report

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